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JAN 82 W T RASMUSSEN, I STEVENS, P D HAYES N66001-78-C-0274

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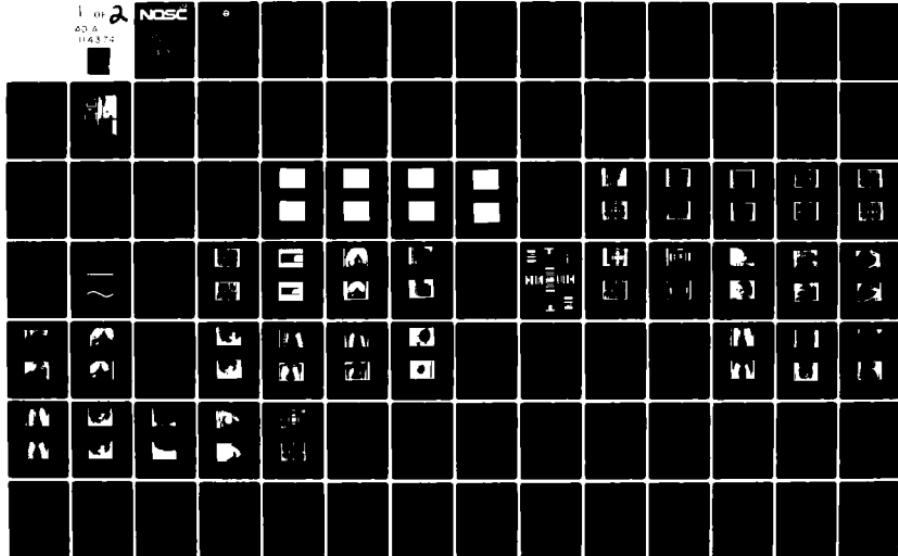
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Technical Report 690

REMOTE MEDICAL DIAGNOSIS SYSTEM (RMDS) ADVANCED DEVELOPMENT MODEL (ADM) AT-SEA TEST RESULTS



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January 1982

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This Technical Report is one in a series of reports for the Remote Medical Diagnosis System (RMDS), Program Element 64771N, Project M0933-PN (NOSC 512-CM38), sponsored by the Naval Medical Research and Development Command, Code 45. It contains the test results of an at-sea evaluation of the RMDS Advanced Development Model (ADM) terminals. This report was prepared by the NOSC Bioengineering Branch (Code 5123) and WESTEC Services, Inc. (Contract N66001-78-C-0274). The at-sea evaluation testing described in this report was conducted from 23 February to 5 March 1978, with one ADM terminal aboard USS ENTERPRISE (CVN 65) and the other terminal located at NOSC. Principal investigators were I Stevens and PD Hayes (NOSC, Code 5123), and J West (WESTEC Services, Inc.), under the direction of WT Rasmussen, Head, Bioengineering Branch (NOSC, Code 5123).

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report provides the results of at-sea experimental evaluation of video transmissions of radiographs over the Remote Medical Diagnosis System (RMDS) advanced development model terminals. The objectives of this evaluation were (1) to obtain quantitative and qualitative data on the functional parameters of the RMDS ADM terminals and components, (2) to define design risks associated with the current approach to RMDS implementation, and (3) to provide baseline data to support follow-on procurement of RMDS engineering development model (EDM) terminals.		

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OBJECTIVE

Obtain quantitative and qualitative data on the functional parameters of the RMDS ADM terminals and components, define design risks associated with the current approach to RMDS implementation, and provide baseline data to support follow-on procurement of RMDS Engineering Development Model (EDM) terminals.

RESULTS

1. RMDS communications via hf and uhf/satellite links were adversely affected by rf noise interference.
2. The RMDS ADM terminals are susceptible to ambient levels of rf noise.
3. Electrocardiogram signal transmission was of sufficient quality for diagnostic purposes.
4. Received stethoscope signals were significantly degraded, especially during hf communications.
5. The quality of video image transmission was good. Two radiologists viewing X-rays received in the digital, fine-resolution mode indicated that the images were of "sufficient quality to permit adequate diagnosis."
6. Waviness was observed in the horizontal axis of the received image when a live image source was employed.
7. Human factors engineering problems existed with regard to design of the terminal configuration, controls, and method of operation.
8. Balanced transmitter/receiver lines were required for proper RMDS interface aboard ship. Several problems were encountered in the interface between the RMDS shore station and NAVCOMMSTA San Diego.

RECOMMENDATIONS

For procurement of future RMDS Engineering Development Models (EDMs):

1. Devise transmission filters or other means to eliminate excessive rf noise interference during hf and uhf/satellite data transmissions.
2. Shield the EDM terminals or employ other design changes to protect the terminals from high levels of ambient rf noise.
3. Consider only digital transmission for video imagery.
4. Design the system to have a minimum video resolution of 525 lines by 256 pixels, with 6 bits per picture element (525 x 256 x 6), and to have a preferred resolution for more detailed radiographs of 525 x 512 x 8.
5. Eliminate the waviness encountered in video image transmission through use of a video disc recorder.
6. For the RMDS EDMs, employ a transmission scheme less sensitive to hf channel characteristics to attenuate rf noise interference in the stethoscope mode.
7. Incorporate human factors engineering design criteria into the EDMs.
8. Provide balanced transmitter/receiver lines for the RMDS interface aboard ship. Use a telephone terminal interface for NOSC/NAVCOMMSTA data communications, as recommended in NOSC TR 631.

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SECTION 1

INTRODUCTION

1.1 PURPOSE

This report contains the test results of an at-sea evaluation of the Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) terminals, conducted from 23 February to 5 March 1978. These at-sea tests were conducted between USS ENTERPRISE, operating in the eastern Pacific waters off the coast of California, and the Naval Ocean Systems Center (NOSC), San Diego. An RMDS ADM terminal was located at each site.

The objectives of the at-sea tests were to obtain quantitative, qualitative, and human factors performance data on the functional parameters of the RMDS ADM terminals and components and to identify probable difficulties associated with operational use of the RMDS. It is intended that the data presented herein be interpreted in conjunction with the results of the RMDS laboratory tests conducted subsequent to the at-sea tests; RMDS laboratory test results are contained in NOSC TR 691 (ref 1).

At-sea testing of the RMDS ADMs specifically addressed the following test objectives:

- a. Evaluate each type of communication channel available to the RMDS within an actual operational environment, and identify problems associated with the use of each.
- b. Determine what problems are encountered in interfacing each of the RMDS terminals to communications equipment aboard ship and ashore.
- c. Demonstrate the operational utility of the electrocardiogram (ECG), stethoscope, and image signal transfer capabilities of the RMDS ADM design.
- d. Measure certain performance parameters of the ECG, stethoscope, and video components of the RMDS terminals.
- e. Assess human factors performance pertinent to the design and operation of the RMDS ADM configuration.
- f. Determine the utility of a remote video camera for viewing patients in the course of diagnostic analysis.

In this document, the results of the at-sea testing are discussed, conclusions are drawn concerning the RMDS performance, and recommendations are presented for future

1. NOSC TR 691, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Laboratory Test Results, WT Rasmussen, I Stevens, PD Hayes (NOSC), J West, and FW Hutzelman (WESTEC Services, Inc.), January 1982.

RMDS test equipment design. The test plan and guidelines for this evaluation are contained in NOSC TR 691 (ref 2).

1.2 BACKGROUND

The mission of the RMDS is to improve medical diagnosis at remote sites. This is accomplished by transmitting medical data and diagnostic information between remote ship or shore sites and full-capability medical centers. The RMDS will enable the medical personnel at a remote site to contact a physician at a diagnostic center (ashore or shipboard) and transmit a visual and auditory presentation of the medical data needed for diagnosis, such as patient history, laboratory tests, ECG tracings, X-ray images, images of a patient injury, heart-lung sounds, and verbal descriptions. By return link, the physician will be able to send diagnosis and treatment information. The communication requirements are satisfied by any two-way, voice-grade, narrow-band communication channel such as telephone line, hf or uhf radio, or a satellite link.

Shipboard feasibility tests of an early RMDS prototype were completed during FY 75/76. This testing showed that the concept was feasible and that equipment could be developed to meet the requirements by using available technology (ref 3). Because of various constraints (narrow bandwidth, short transmission times, etc), the resolution and gray scale to be achieved in transmitting and displaying radiographic data should be kept to a minimum to meet essential requirements. To establish the minimum acceptable resolution, a radiology study with eight radiologists was conducted in FY 77 in which a special digital closed-circuit television system was used to simulate the RMDS equipment (ref 4).

As a result of those feasibility and radiology tests, NOSC undertook a development project to produce two Advanced Development Model RMDS terminals; the ADMs were procured in September 1977. The ADMs were tested at sea, with one terminal aboard USS ENTERPRISE (CVN 65) from 28 February to 5 March 1978; at-sea test results are documented in this report. The RMDS ADM terminals were tested for technical performance at NOSC from September 1977 to September 1979; RMDS laboratory test results are documented in NOSC TR 691 (ref 1). Image fidelity evaluation testing of radiograph transmission via the ADMs was performed during the period October 1978 to April 1979; those test results are documented in NOSC TR 683 (ref 5).

-
2. NOSC TD 395, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Test Plan, WT Rasmussen, I Stevens (NOSC), and J West (WESTEC Services, Inc.), December 1980.
 3. NOSC TR 659, Feasibility Tests of the Remote Medical Diagnosis System, WT Rasmussen, I Stevens (NOSC), and JA Kuhlman (WESTEC Services, Inc.), January 1981.
 4. NOSC TR 150, Resolution Requirements for Slow-Scan Television Transmission of X-rays, WT Rasmussen (NOSC), RL Crepeau (WESTEC Services, Inc.), and FH Gerber (NRMC San Diego), 19 September 1977.
 5. NOSC TR 683, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Radiology Performance Test Results, WT Rasmussen, PD Hayes, I Stevens (NOSC), FH Gerber (NRMC San Diego), JA Kuhlman, and FW Hutzelman (WESTEC Services, Inc.), January 1982.

1.3 SYSTEM DESCRIPTION

The system as a whole consists essentially of the RMDS terminals, the existing voice-grade communication links used to interconnect the terminals, and user personnel. Contained in the terminals is all the hardware that is unique to the system: TV camera, TV monitor, X-ray light box, electronic stethoscope, ECG monitor, audio tape recorder, audio handsets, and the electronics package, consisting of signal modulator, demodulator, and modems. Figure 1 illustrates the RMDS Advanced Development Model.

Two RMDS terminals have been designed: one for shipboard use, the other for shore use. The two terminals are essentially identical except for the capability to link to the basic interunit communication channel. The shore terminal uses a dial telephone for establishing landline communications to rf communication centers. The shipboard terminal also contains an intercom unit to interface with radio central. The shipboard terminal interfaces with Navy communications equipment via a C1138B/UR. Both terminals are functionally capable of sending and receiving ECG traces, stethoscope sounds, and radiographic and patient images. In addition, each terminal provides a capability for voice communication with another RMDS terminal over the data channel (on a shared channel basis) or an auxiliary channel. The RMDS terminals themselves do not incorporate any rf communications equipment; they rely on equipment available on ship or ashore. The function and operation of the ADM terminal are described in NOSC TD 397 (ref 6).

The RMDS terminal consists of the following principal components, as depicted in figure 1:

- Main television camera (KGM Model 113T) with a Canon Model V6X16R(DC) zoom lens and supporting stand
- X-ray viewbox
- Main TV monitor* (17" Electrohome, Model EVM 171OR)
- Audio tape recorder for recording transmission line signals (Sanyo Model RD4553)
- Control panel, including transmit/receive data selection, camera controls, system controls, panel microphone and speaker controls, external and internal voice communication controls, and voice communication handsets
- Video transmit unit, including video disc recorder (Modified CVI Model 260B)

6. NOSC TD 397, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Operator's Manual, WT Rasmussen, PD Hayes, I Stevens, EW Davenport (NOSC), and JA Kuhlman (WESTEC Services, Inc.), July 1981.

*The shore RMDS terminal may have a second TV monitor for simultaneous display of two images.

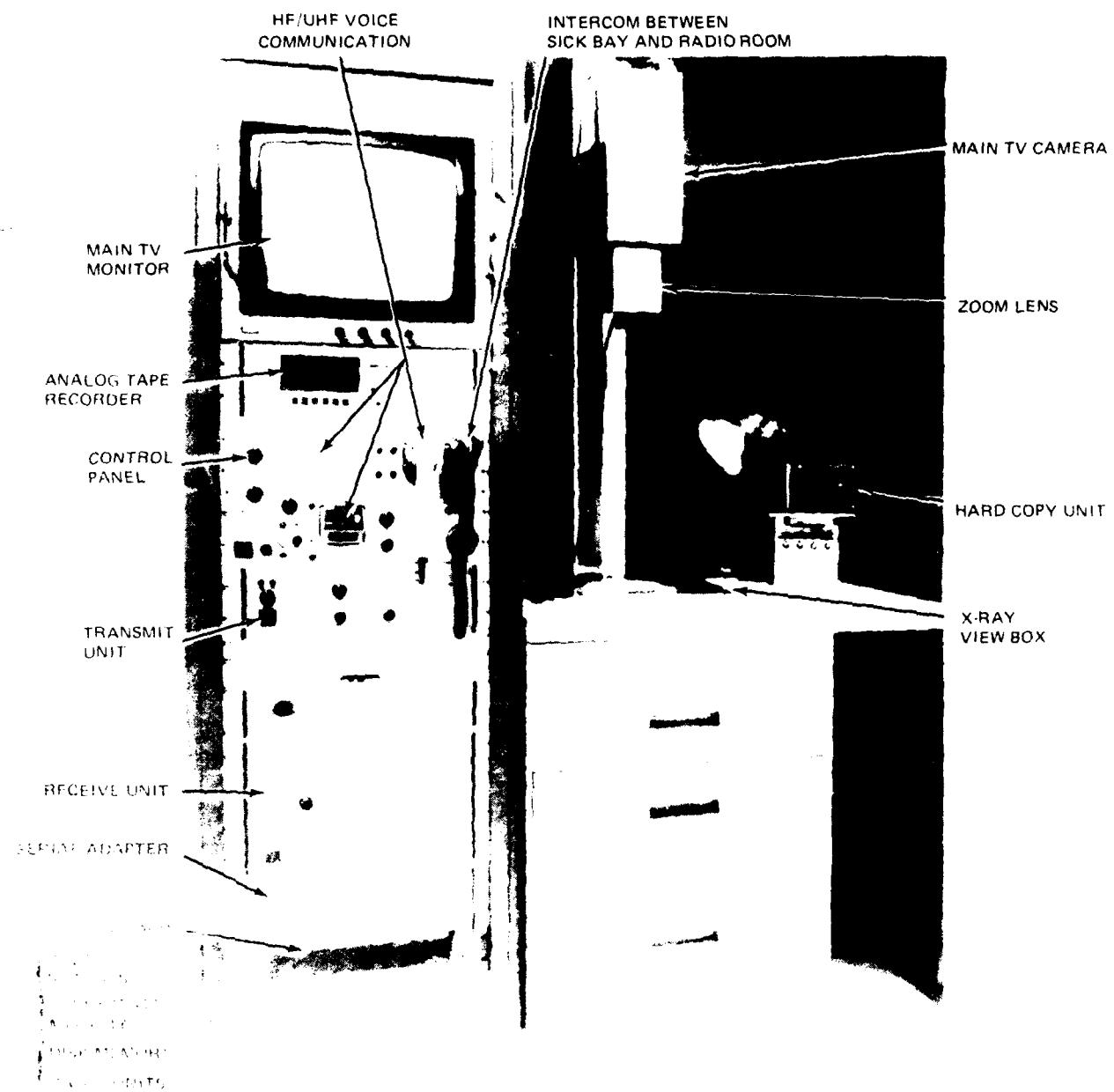


Figure 1 Advanced Development Model (ADM) RMDS terminal and related components.

- Video receive unit, including solid-state memory for up to 525 x 256 picture elements at 6 bits per picture element (Modified CVI Model 275)
- Hard-copy unit, consisting of 5" auxiliary TV monitor and Polaroid camera
- ECG strip chart recorder (MFE Corp. Model M-21) (not shown)
- Serial adapter
- Modem (Model ICC 24) 2400 bps
- Two radio control units (C1138B/UR)
- Remote TV camera, including monitor, tripod, zoom lens, 50 feet of cable, and padded carrying case (not shown)
- Stethoscope pickup unit (not shown)
- ECG machine (Model HP 1500B) (not shown)
- Mounting racks and miscellaneous hardware

SECTION 2

TEST CONSIDERATIONS

2.1 SUMMARY OF TESTS AND PROCEDURES

Repeated qualitative and quantitative tests were performed to assess the at-sea operational utility of the electrocardiogram, stethoscope, and video image transfer modes of the RMDS, over two communication channels:

- Hf (high frequency)
- Uhf/satellite (ultrahigh frequency/satellite)

Each qualitative test required that an appropriate communications link be established between ship and shore. With the link thus established, a simulated electrocardiogram, stethoscopic sound, or video image was transmitted from the ship to the NOSC laboratory.

A Parke-Davis 3175 ECG signal source was used for ECG transmission; from this, five different ECG lead configurations were generated. These transmitted data were received by personnel at the NOSC RMDS terminal. An instrumentation quality tape recorder was used to transmit stethoscopic sounds from the USS ENTERPRISE RMDS terminal to the NOSC RMDS terminal. At NOSC the transmissions were recorded on another instrumentation quality tape recorder for subsequent qualitative evaluation of heart sounds. Video image sources (including radiographs, a resolution measurement test pattern, hardcopy photographs, ECG tracings, and typed text) were transmitted from both the main and remote cameras of the RMDS terminal aboard ship to the shore-based RMDS terminal. All transmitted images were photographically recorded by the transmitting and receiving terminal operators for subsequent comparison and analysis.

The quantitative tests for ECG, stethoscope, and video image information transfer were established in anticipation of the need to further document technical design issues for the RMDS under operational conditions. These quantitative tests included measurements of noise and harmonic distortion for received ECG and stethoscope signals, signal-to-noise ratio (SNR) for received video signals, and dc drift for received ECG transmissions. Stethoscope and ECG measurements were taken while using an hf communication link, and video SNR measurements were obtained for both hf and uhf/satellite communication links.

All tests delineated in the previously established test plan (ref 2) were performed. However, two factors influenced data transmission at sea:

- a. The availability of communication channels.
- b. The total time available to conduct RMDS testing relative to the operational schedule and/or priorities of USS ENTERPRISE and its personnel.

These factors dictated almost exclusive utilization of hf communications, with limited uhf/satellite communication and no uhf communication available. While the test plan specified performance of each test five times, fewer than five of each were actually performed. The test plan also required that one test of each mode of RMDS operation be received, recorded, and played back from a Sanyo Model RD4553 audio tape recorder. The tape recorder designated for this purpose failed prior to installation of the equipment on the ship, and this portion of the testing could not be accomplished. A significant feature of the at-sea testing not required by the test plan but performed nevertheless was the successful recording of a 12-standard-lead human ECG; the test plan required only that simulated ECGs be transmitted and received. The human ECG transmitted by personnel aboard USS ENTERPRISE verifies the clinical utility of RMDS ECG transmissions. An index of the at-sea tests performed appears as table 1.

<u>At-Sea Test</u>	<u>Number of Performances</u>
Qualitative Testing of ECG Signal Transmission	4*
Harmonic Distortion of ECG Signal Transmission	5
Noise Level in ECG Signal Transmission	5
Qualitative Testing of Stethoscope Signal Transmission	1
Harmonic Distortion of Stethoscope Signal Transmission	3
Noise Level in Stethoscope Signal Transmission	4
Qualitative Testing of Main Camera Image Transmission	4
Qualitative Testing of Remote Camera Image Transmission	3
Signal-to-Noise Level in Image Transmission	4

*One human ECG and three simulated ECG signals

Table 1. Index of RMDS at-sea tests.

2.2 FACILITIES AND CONDITIONS

2.2.1 Shipboard Configuration and Environment

The RMDS terminal was located in the sick bay aboard USS ENTERPRISE. Figure 2 illustrates the equipment interface used for RMDS testing aboard ship. Digital data from the RMDS terminal passed through a 2400 bps modulator-demodulator (modem) integral to the RMDS terminal; the data were routed to the communications center via C1138B/UR radio control units and communications lines especially installed for these tests. Shipboard environmental conditions were less than optimal in the following respects:

- a. Electromagnetic interference.
- b. The ship's sick bay was located directly under the hangar deck, adjacent to aircraft elevators. As such, the area was subject to high levels of audible noise and vibration.

2.2.2 Shore Configuration and Environment

Figure 3 illustrates the equipment interface ashore as originally intended. As shown, the RMDS equipment was designed to employ a half-duplex, two-wire telephone line to the Naval Communications Station (NAVCOMMSTA). Because of feed-back problems at the interconnecting switchboard (ICSB) and at the 758 hybrid (two-to-four line converter), it was necessary to modify the system to full duplex capability for communications with NAVCOMMSTA. A direct-dial telephone line was used to transmit information between NAVCOMMSTA and NOSC, and a second dedicated telephone line between these two facilities was used to receive information, as illustrated in figure 4.

During the testing, radio frequency (rf) noise was present at the NOSC RMDS facility. In order to identify the characteristics of this noise, a 3-foot length of twisted-pair wire (terminated in 600 ohm resistance) was used for the measurement, in conjunction with the oscilloscope. Three types of noise of unknown origin were identified:

- Random 1.5-2.0 volt (p-p) noise spikes
- A periodic 30-60 millivolt, 1.0 MHz communications signal with 20.0 MHz coding
- Random 10 millivolt, 60 Hz noise

The first two types of interference were reduced at the RMDS phone jack outputs with the addition of a 1000 pF capacitor.

The satellite communication link tests required that the RMDS terminal be located in a secure area near the encryption/decryption devices at NOSC. Figure 5 illustrates the equipment configuration for satellite communications needed in support of RMDS testing at NOSC.

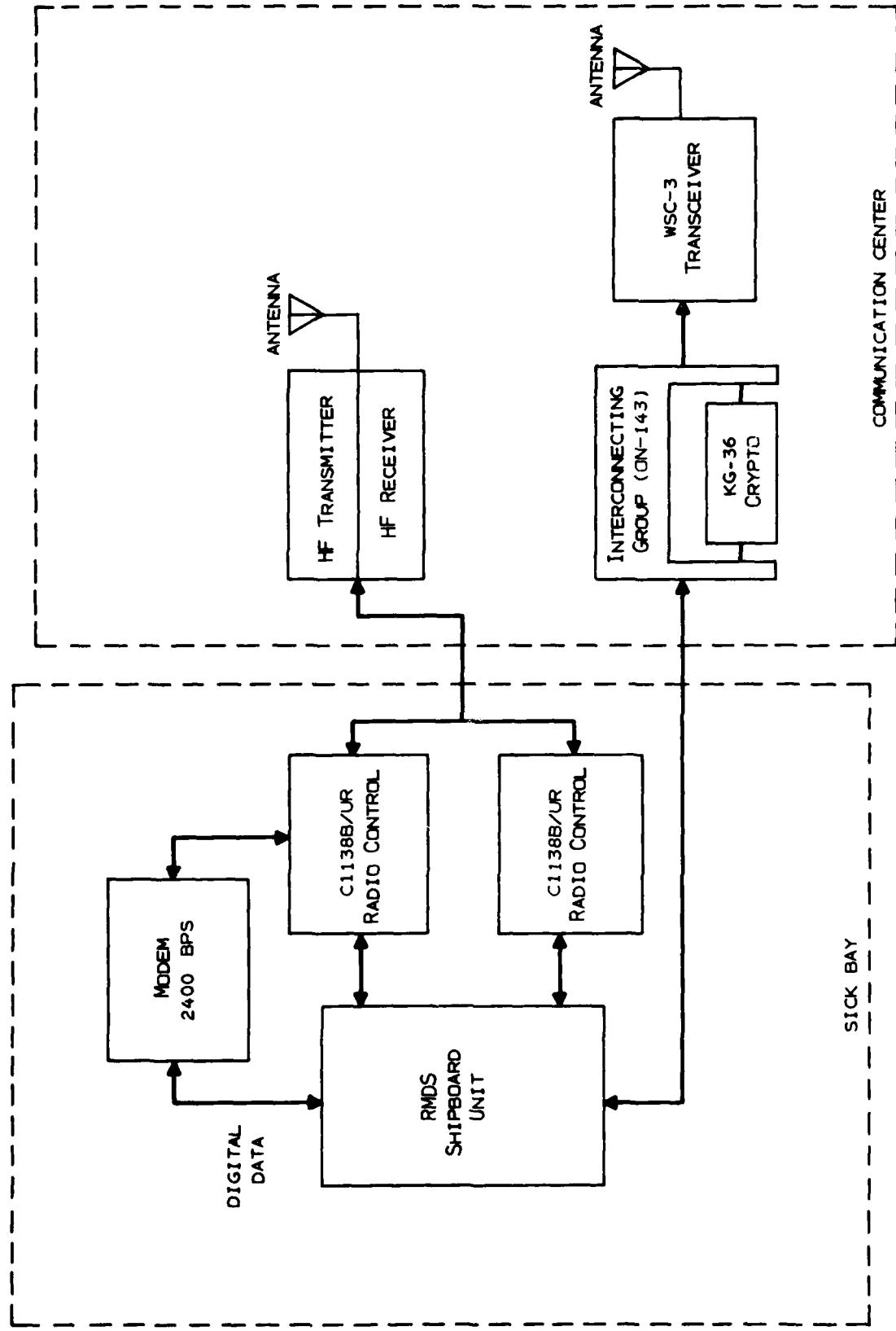


Figure 2. RMDS equipment interface aboard USS ENTERPRISE.

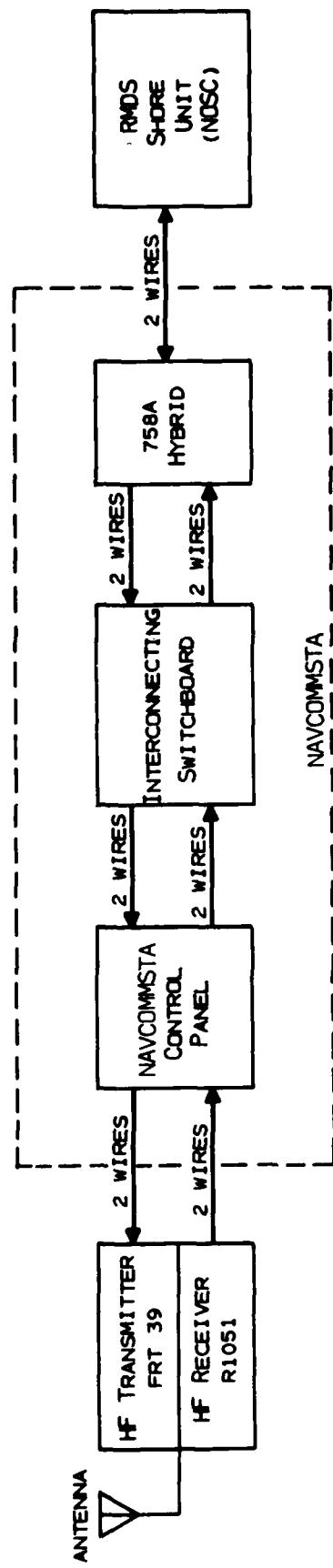


Figure 3. Intended RMDS equipment interface for hf communication on shore.

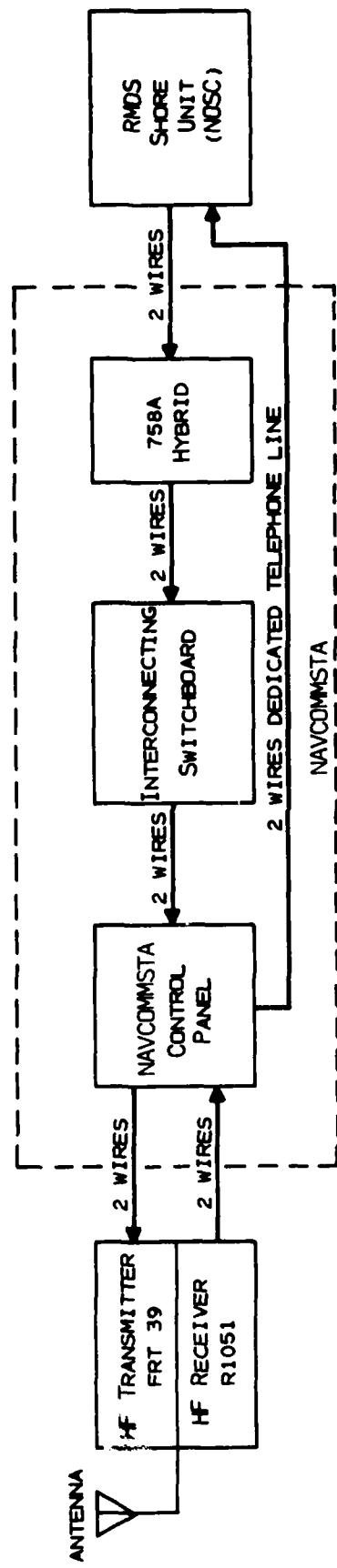


Figure 4. Actual RMDS equipment interface for hf communication on shore.

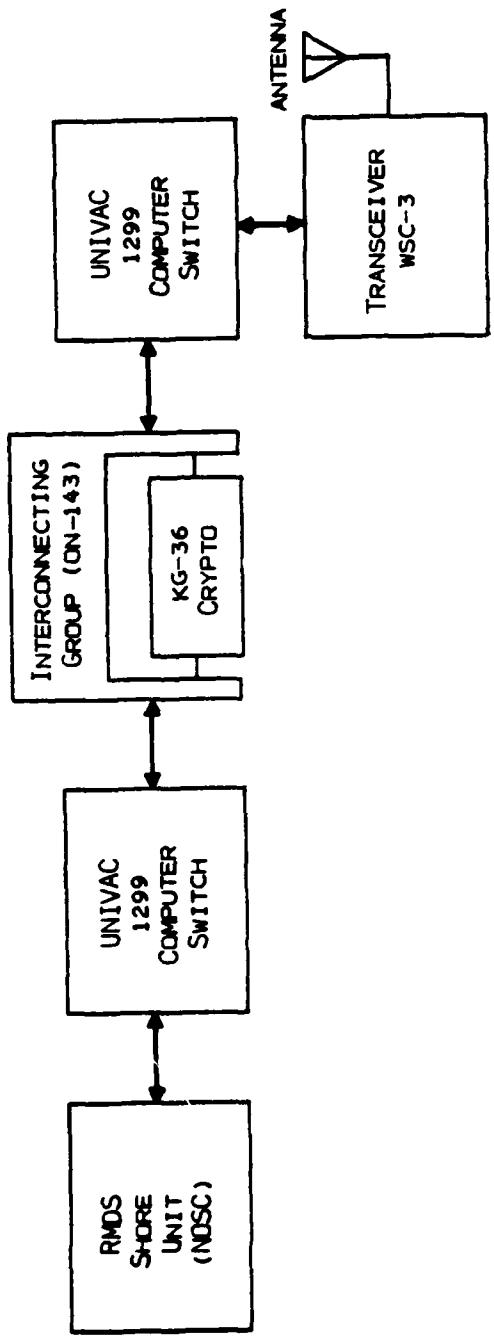


Figure 5. RMDS equipment interface for satellite communication on shore.

2.3 COMMUNICATIONS LINK ESTABLISHMENT

2.3.1 Hf Communications

An hf half-duplex link was used for voice and data communication transmission during RMDS at-sea tests. The hf radio link experienced a number of problems. First, there existed considerable difficulty in obtaining a frequency that was relatively noisefree and acceptable for data transmission. Before each test, several frequencies were tried before relatively good hf communications were established between the ship and NAVCOMMSTA, San Diego. This activity routinely took between 90 minutes and 3 hours for each test. Second, hf noise interferences, particularly burst noise and interferences from adjacent frequencies, disrupted RMDS testing. The RMDS response to these interference noises is discussed in a later section of this document. In cases of hf noise interference, new frequencies had to be obtained and communications established, thereby causing additional delays of an hour or more. The average time required to establish communications between ship and shore was 2 hours. Voice communication, once established, was reported as "poor" in 16 cases, "fair" in 2 cases, "good" in 24 cases, and "excellent" in 1 case when operating in the hf link.

2.3.2 Uhf/Satellite Communications

A major problem in using the uhf/satellite communications link for testing was that of obtaining permission to use a narrowband satellite channel. During satellite data transmission of images, an hf communication link was used for audio communications. Radio frequency interference occurred during image transmission via the uhf/satellite communication link. When the interference was weak, a few scanning lines appeared to be lost. With strong rf interference, cryptographic equipment synchronization was lost and the whole image had to be retransmitted.

2.3.3 Uhf Communications

No uhf radio links were used during at-sea testing because all uhf transceivers aboard USS ENTERPRISE were being used for operational activities during the RMDS test period.

2.3.4 Equipment Interface

A C1138B/UR radio control unit provided the interface between the RMDS terminal and the communications equipment. It was determined that balanced transmit and receive lines were necessary for proper interface. Furthermore, all lines were required to be floating with respect to ground; ie none of the lines going into the transmitter or receiver could be grounded since the type of equipment used determines ground voltage.

Several problems arose in trying to interface the RMDS shore terminal with communications equipment at NAVCOMMSTA, San Diego. Figure 3 illustrates the intended equipment interface on shore. When this arrangement was attempted, the signal loss was about 30 dB. As the signals from NAVCOMMSTA to NOSC were amplified, the transmitter would turn on (key) and a feedback loop would form that resulted in a disruptive "ringing" noise during ship-to-shore communications. In addition, the received hf noise spontaneously keyed the transmitter in the absence of a signal, thus initiating a feedback loop. Four solutions in combination were attempted to minimize feedback problems:

- a. Lowered Signal Strength. An attempt was made to lower the received signal strength to control feedback noise. However, there existed almost 30 dB signal loss between NAVCOMMSTA, San Diego and NOSC. A minimum loss of 16 dB was encountered in the direct-dial telephone line; the rest of the signal loss occurred when the signal was passed through ICSB and 758 hybrid. Lowered signal strength resulted in less feedback but poor communications.
- b. Manual dc Key. A spare dc keyline was used to manually control the transmitter in an attempt to alleviate the feedback problem. Such an approach proved unacceptable, as it required an additional person to key and unkey the transmitter.
- c. Voice Activated Relay. A voice activated relay circuit was installed in an attempt to preclude noise-related keying of the transmitter. Typically, the sensitivity of this circuitry had to be narrowed so as not to be triggered by noise; as a result, poor communications resulted.
- d. Modified Equipment Interface. The equipment interface illustrated in figure 4 reduced the feedback problems discussed above but did not eliminate them. Disruptive "ringing" was present for shore-to-ship communication, and the signal levels had to be reduced.

2.4 EQUIPMENT MODIFICATION

The following equipment modifications were effected during RMDS at-sea testing:

- a. Because of feedback which existed between the RMDS speaker and microphone aboard ship, the speaker was disconnected and a headset and/or handset was used instead.
- b. Shipboard transmit and receive transmission line pairs were not balanced, and the cable run between the sick bay and the ship's communications center was about 700 feet long. Isolation transformers (600 ohms) were installed on both transmission lines to alleviate this situation.
- c. Both radio control units (C1138B/UR) aboard ship were connected to chassis ground via pin 7 on TB 101. However, shipboard transmitters and receivers determine and supply ground voltages, which may change depending upon the communications equipment in use. Because the lines between the communications center and the sick bay were grounded in this manner, pin 7 on TB 101 was disconnected from chassis ground on both C1138/UR radio control units.
- d. During video reception, hf noise repeatedly caused restart of the received image; this resulted in the loss of already-received portions of the image. A switch to disable the autostart function was installed on both ship and shore RMDS terminals to prevent this restart.

- e. When a received analog or digital image was displayed on the monitor with the RMDS mode switch left in RECEIVE, hf noise would drop the RMDS terminal into the receive mode. This drop into receive would "tear" the displayed image and render it useless. To prevent this occurrence, a RECEIVE HOLD switch was installed on the shore-based terminal.
- f. Both ship and shore RMDS terminals were installed with alarm and reset circuits for use during satellite testing. These circuits indicated alarm conditions at the crypto unit, which then required remote reset of the RMDS terminal at the crypto in the communications center.
- g. The RMDS shore terminal was installed with an operator-controlled volume adjustment for use in receiving stethoscope sounds.

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SECTION 3

QUALITATIVE SYSTEM PERFORMANCE

The subsections that follow address the clinical utility of data transmitted and received by the RMDS ADMs. ECG, stethoscope, and video image data were tested at sea for qualitative performance. Problems with equipment interface, communications variables, and system operation were noted.

3.1 ELECTROCARDIOGRAM

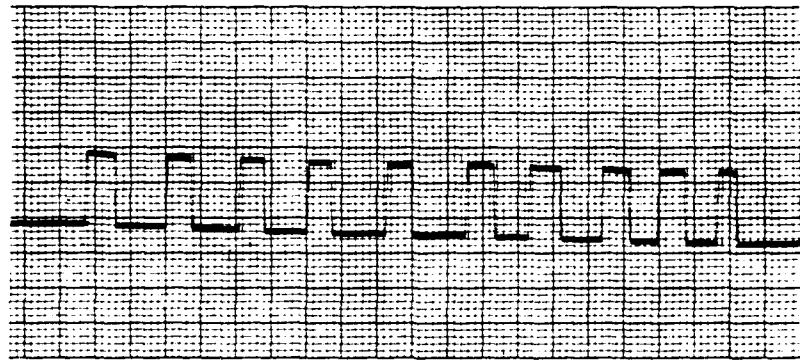
Testing was conducted to assess the qualitative ability of the RMDS terminals to transfer usable ECG signals. Operators at the transmitting and receiving sites were asked to complete a series of test data sheets for each test conducted. All respondents indicated that the ECG equipment operated as expected. The tape recorder intended for use in the recorded playback of transmitted ECGs was inoperable, and thus no ECG playback recordings were performed. Representative strip chart recordings from both the transmitting and receiving sites, showing calibration pulses, simulated ECG, and human ECG, are contained in figures 6 through 8, respectively.

The ECG data were transmitted and received relatively faithfully in terms of amplitude and frequency, although attenuation of the signal was observed at the receiving terminal. The attenuation was manifested as a decrease in pulse height, indicated by points A through E of the received ECG signals of figure 7. The decrease in pulse height ranged from 6 to 16%, with low-frequency and negative pulses (points C and E of figure 7, respectively) showing the larger decrease in pulse height. Similar signal attenuation had been reported in laboratory testing of the RMDS terminals (ref 1).

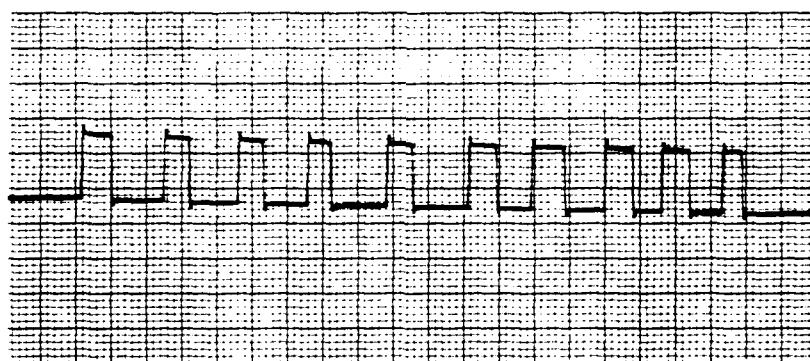
Overshoot of about 10% was measured on the received calibration pulses (figure 6). This overshoot accounted for the difference in attenuation for high- and low-frequency pulses (points B and C of figure 7, respectively), since overshoot would decrease the amount of attenuation observed on high frequency pulses. A 1% increase in the distance between pulses, ie between points A and D of figure 7, was observed for the received signals. The increase was proportional for all elements of the received signal and did not represent significant signal distortion. In general, it was felt that the quality of the received ECG data was good and of a level sufficient for diagnostic purposes.

3.2 STETHOSCOPE SOUNDS

Testing was conducted to determine the qualitative ability of the RMDS terminals to transfer usable stethoscopic signals via an hf communication link. The stethoscope sounds transmitted during the testing were provided from a tape recording of an LP record of heart sounds used as a physician's teaching aid. For the purposes of this testing, only the heart sounds from the record were taped; accompanying discussions of classic pathologic conditions were omitted. At the transmitting (shipboard) terminal, the HP 3960 instrumentation tape recorder output was patched into the



(a) Transmitted calibration pulse



(b) Received calibration pulse

Figure 6. Traces of calibration pulse for simulated ECG transmission/reception.

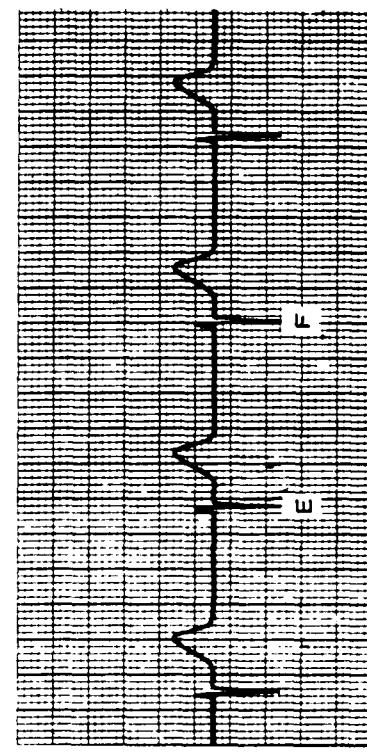
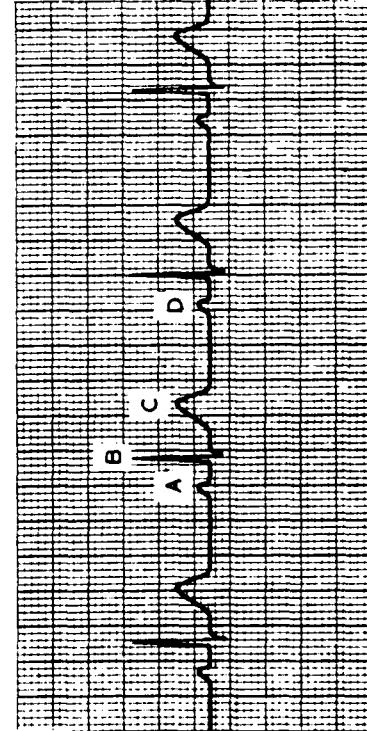
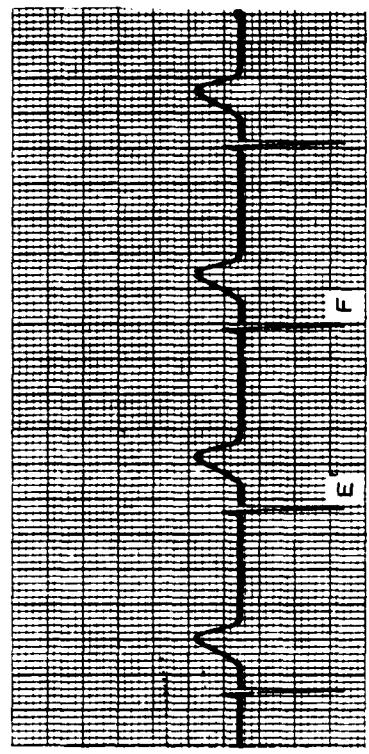
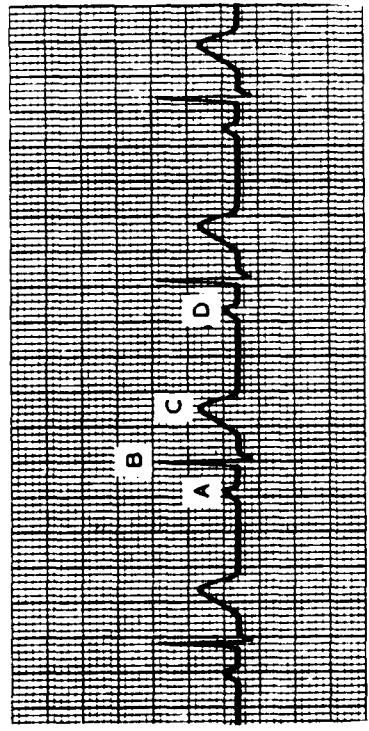
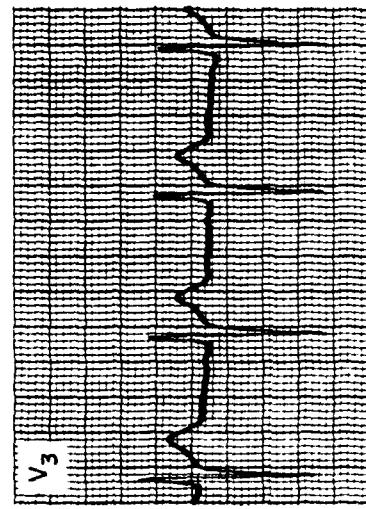
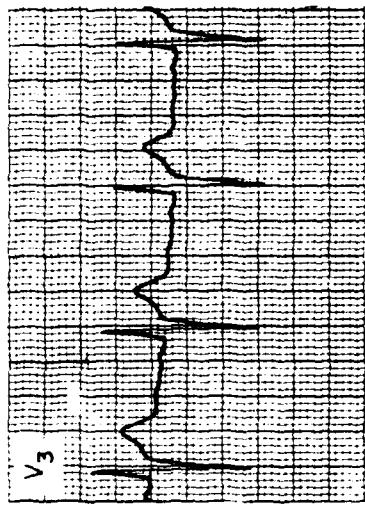
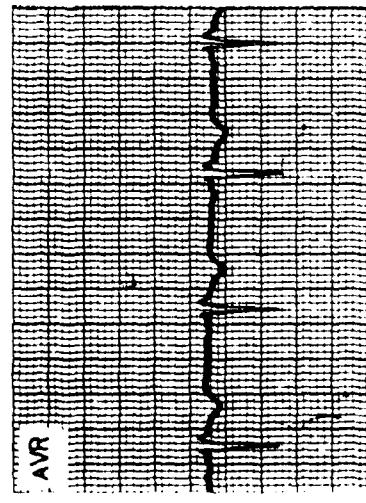
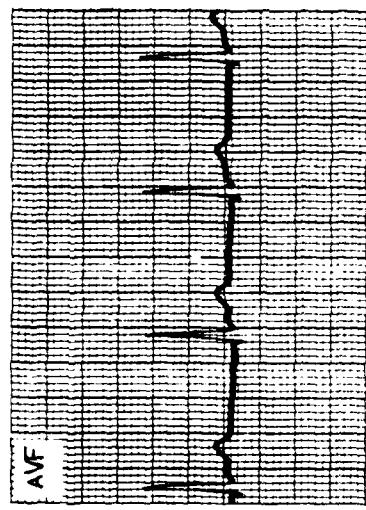


Figure 7. Traces of simulated ECG transmission/reception.



(a) Transmitted ECG signal



(b) Received ECG signal

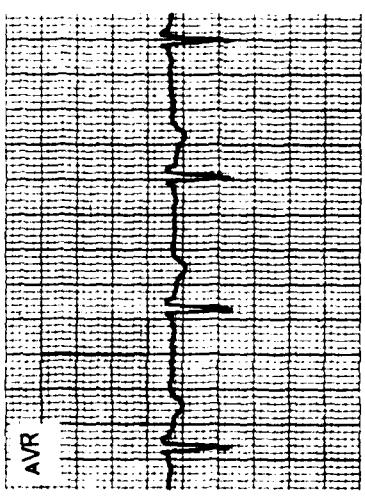
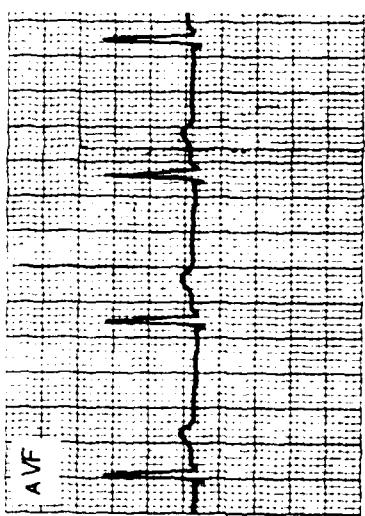


Figure 8. Traces of human ECG transmission/reception.

stethoscope input, and the prerecorded heart sounds were transmitted via an hf communication link. The transmitted and received sounds were recorded on an HP 3960 instrumentation recorder for subsequent analysis. This analysis consisted of comparison of the transmitted and received signal spectrums and qualitative assessment of the received signal by a medical specialist.

Figures 9 through 12 show representative photographs of the spectral analysis for transmitted and received heart sound recordings. Appendix A identifies the alphanumeric symbols present on the spectral analysis photographs. In general, the received heart sounds were similar in amplitude and frequency to the transmitted sounds, as indicated in figures 9 through 12. Figures 10 and 12 (spectral analysis, log scale) show good frequency response for the lower frequencies (1 to 100 Hz). A general increase in noise that was observed on the received recording was attributable to the RMDS terminals and the communication link. In addition to this increase in noise, a number of the received signals possessed distinct noise spikes at approximately 60 Hz intervals, as seen in figure 11.

Dr WUR Vieweg, MD, Head, Cardiology Branch, Naval Regional Medical Center, San Diego, reviewed the transmitted and received recordings of heart sounds with respect to the original phonograph record of heart sounds. He felt that the quality of the transmitted tape recordings was at the 85th percentile level with respect to the original heart sound source (a training phonograph record). Dr Vieweg assessed the quality of the received heart sounds as much poorer — at the 40th percentile level. This represents a decrease in quality of 53% for the received heart sounds compared to transmitted sounds.

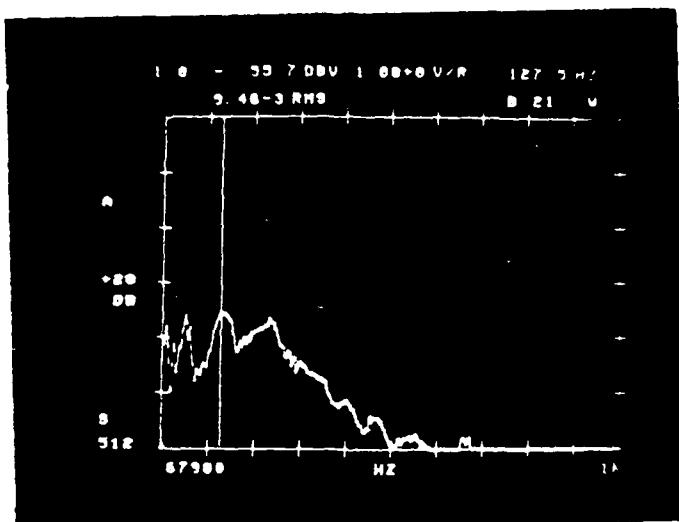
It should be noted that three factors directly contributed to the quality loss experienced in association with stethoscopic heart sounds. First, the number of heart beats per heart defect was limited to a few beats. Under normal conditions, a physician can listen to a significantly larger number of heart beats. Second, the transmitted and received recordings contained background noise, which interfered with the heart sounds. Part of this background noise can be attributed to the RMDS terminals and the communication link, and part to the recording process. Finally, no information was provided as to 1) patient history, 2) physical position of the stethoscope, and 3) additional medical test findings such as ECG, chest X-rays, etc. Stethoscopic sounds not supported by background information do not represent a realistic medical situation.

The low quality of the heart sounds received via hf transmission adumbrates the limited utility of the RMDS for this mode of operation. Stethoscopic digital transmission, less sensitive to the noisy hf channel characteristics, is necessary.

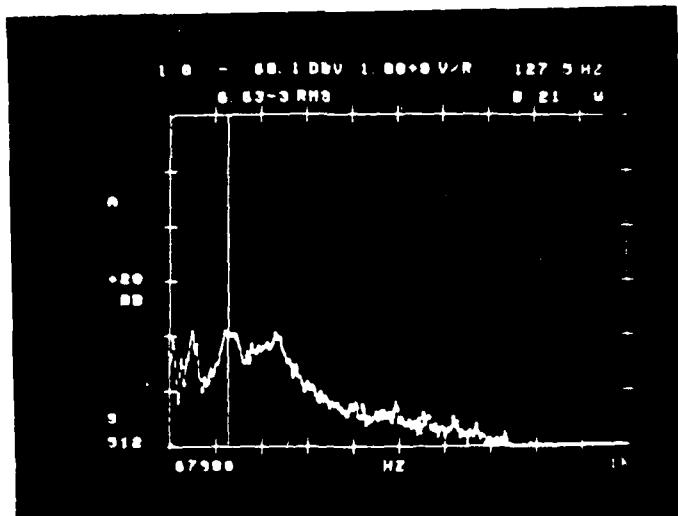
3.3 VIDEO IMAGERY

Qualitative video image tests were conducted to determine the subjective quality of images transferred via the RMDS terminals and hf and uhf/satellite communication links. Both main and remote cameras were used as image sources, and tests were conducted to compare:

- digital and analog transmission modes
- close-up and far fields of view

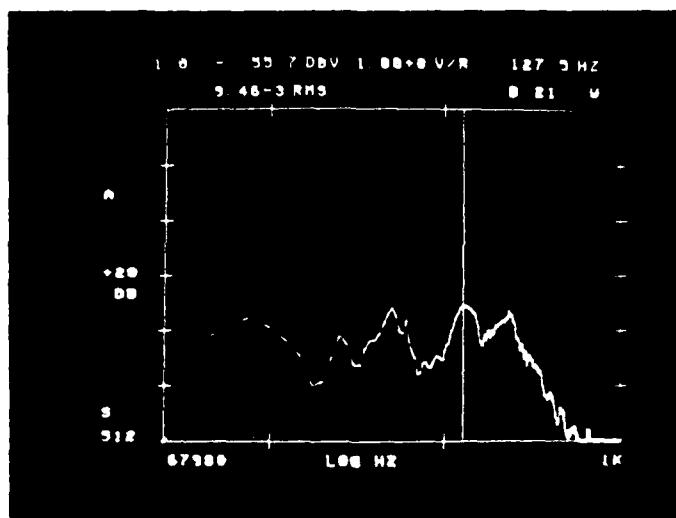


(a) Transmitted recording

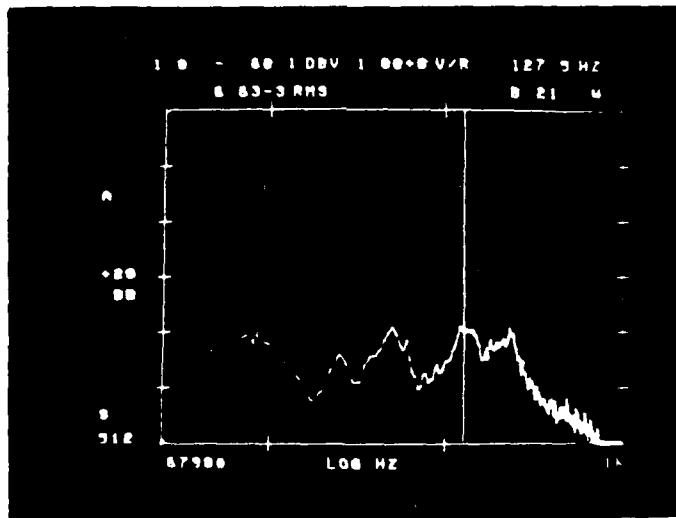


(b) Received recording

Figure 9. Photographs of spectral analysis (linear scale) for transmitted/received recordings of stethoscopic testing, severe constrictive pericarditis.

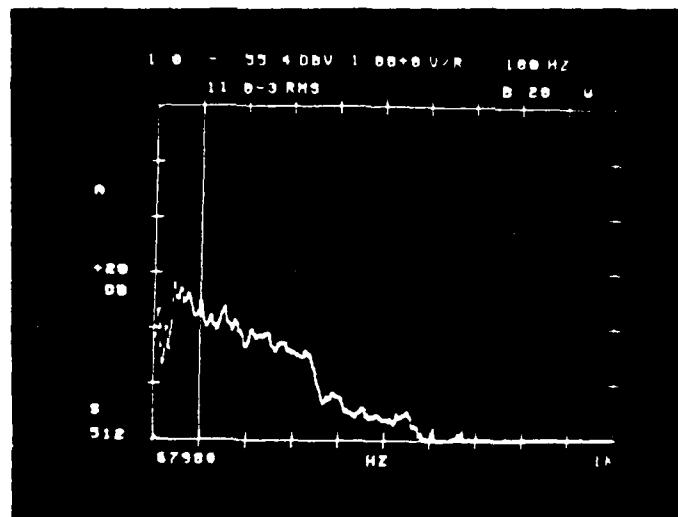


(a) Transmitted recording

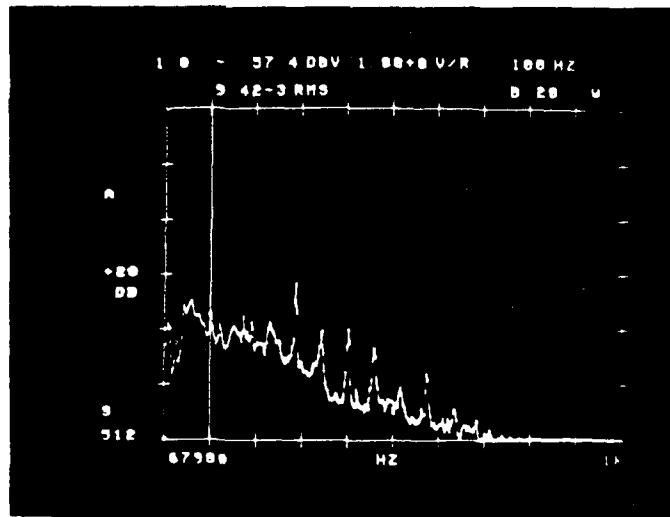


(b) Received recording

Figure 10. Photographs of spectral analysis (log scale) for transmitted/received recordings of stethoscopic testing, severe constrictive pericarditis.

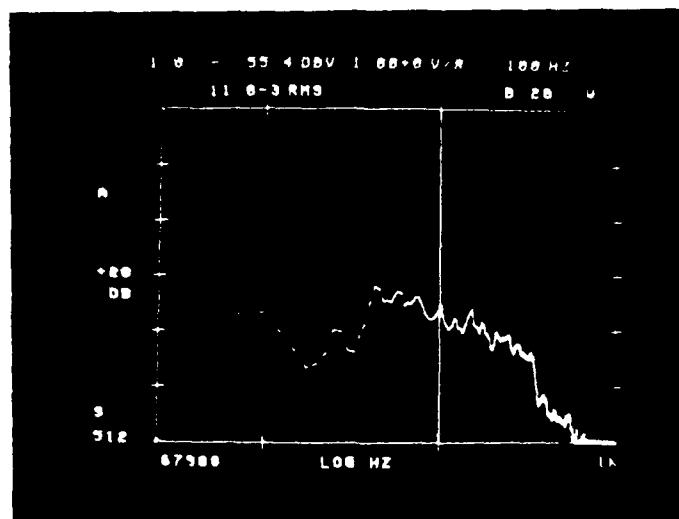


(a) Transmitted recording

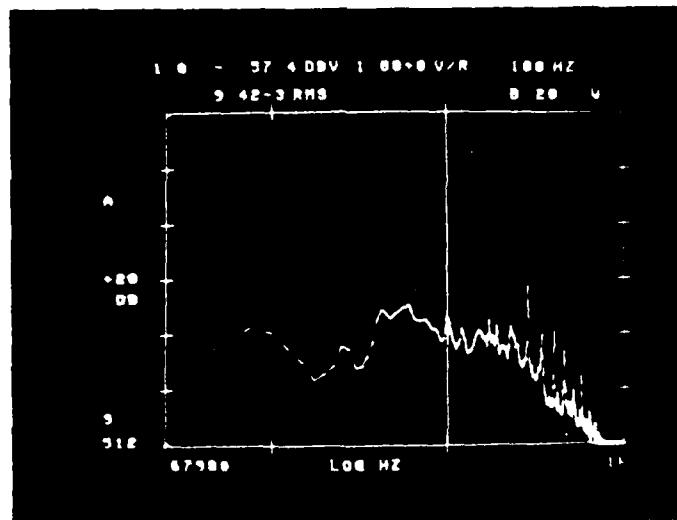


(b) Received recording

Figure 11. Photographs of spectral analysis (linear scale) for transmitted/received recordings of stethoscopic testing, systemic hypertension.



(a) Transmitted recording



(b) Received recording

Figure 12. Photographs of spectral analysis (log scale) for transmitted/received recordings of stethoscopic testing, systemic hypertension.

- fine and coarse resolution
- live and video disc recorder images

Images were photographed by transmitter and receiver operators for subsequent comparison and evaluation.

3.3.1 Analog vs Digital Transmission

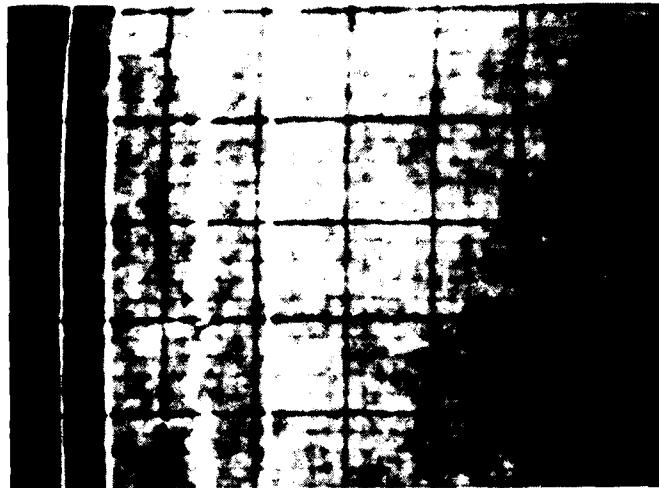
In general, the quality of both analog and digital video transmission was good. Figures 13 through 17 show representative photographs of transmitted/received images of test patterns for the various test conditions over an hf communication link. These reproductions of the photographed images do not show all the slight differences between test conditions, but those irregularities are discussed herein. The photos do demonstrate, however, the nature of the subject material and the qualitative bounds of the differences.

Figures 14 and 15 compare live images and video disc recorded images, transmitted in analog and digital transmission modes. The transmitted image represents a portion of 7 inch x 10 inch graph paper divided into 70 large (1-inch) squares, each of which was further divided into 25 smaller (0.2-inch) squares. The horizontal lines of the live image in both analog and digital transmission modes show waviness caused by camera vibration along the vertical axis. Vibration of the camera aboard ship distorted both analog and digital reception to the same degree. Following is a discussion of the equipment and its vibrational effects.

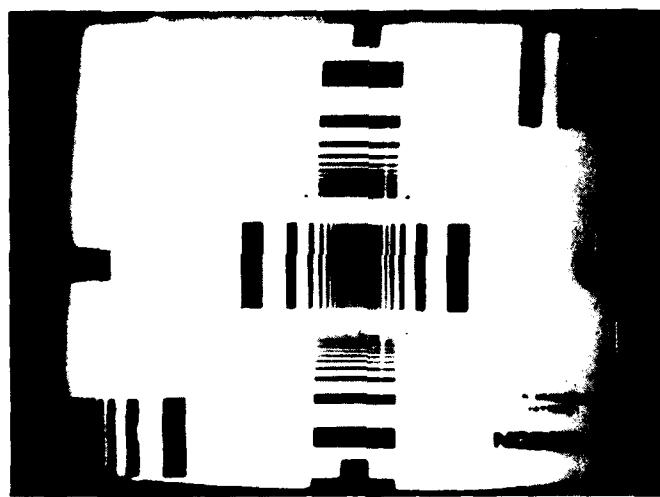
Figure 18 shows the RMDS transmitting terminal as it was installed aboard USS ENTERPRISE. The TV camera, which weighs 8.4 kilograms, was supported by a triangular pole attached to the table top by a steel plate. The RMDS equipment cabinet and camera support pole were secured to three floor-to-ceiling steel beams, with sway braces installed to reduce the effects of shipboard movement (see figure 18). This method proved to be ineffective in reducing camera vibration to a tolerable level.

The maximum vibration observed was approximately 1% of the camera's vertical field of view, representing a distortion of approximately two horizontal lines both above and below the desired scanning position. Figure 19 graphically depicts the horizontal waviness effect of camera vibration along the vertical axis. Reducing camera vibration by 75%, ie to 0.25% of the camera's vertical field of view, would have eliminated waviness by restricting camera scanning to one horizontal line.

To reduce vibrational distortion, the TV camera must remain as stationary as possible with respect to the viewing table. This might be accomplished by the use of sway braces from the top of the camera support pole to the RMDS equipment cabinet. Two additional approaches which may reduce camera vibration are 1) the use of shock/vibration mounts under the RMDS terminal and between horizontal securing braces and 2) a decrease in camera mass. With the TV camera stationary with respect to the RMDS equipment cabinet and viewing table, vibration mounts should result in equal displacement of camera and table, ie no vibrational distortion. The mass of the TV camera contributes to vibration in a fashion similar to a pendulum; thus a reduction in mass should decrease vibration. This could be achieved by the use of a solid-state camera or a conventional camera with separate control panels. In order for the RMDS terminals to meet military specifications, special attention should be directed toward such camera vibration. It should be noted that camera vibration distortion was reduced

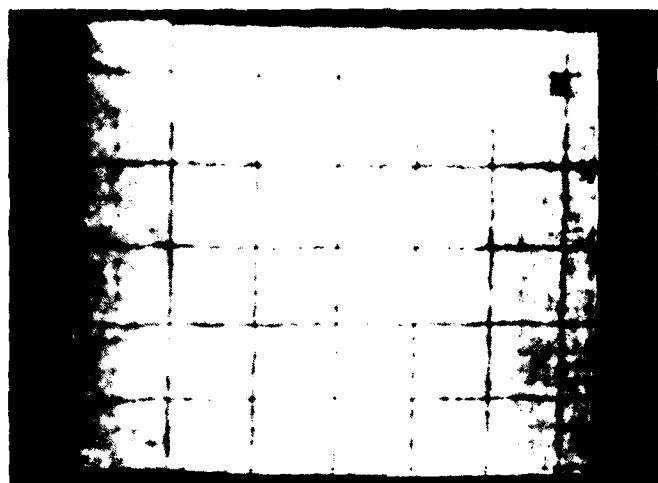


(a) Transmitted image for figures 14 and 15.

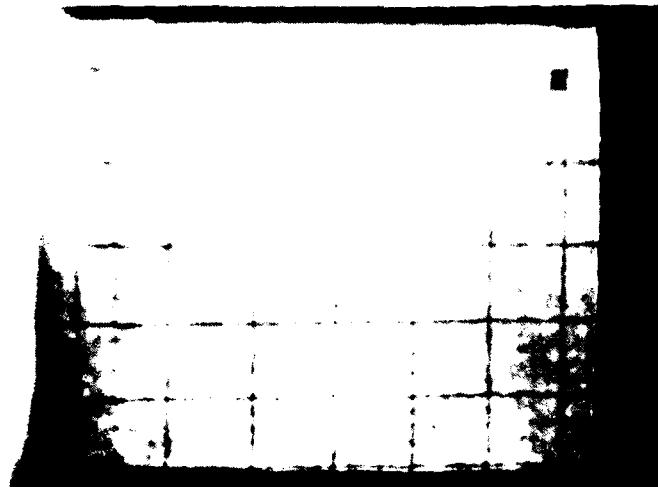


(b) Transmitted image for figures 16 and 17.

Figure 13. Transmitted image of test patterns for figures 14 through 17.

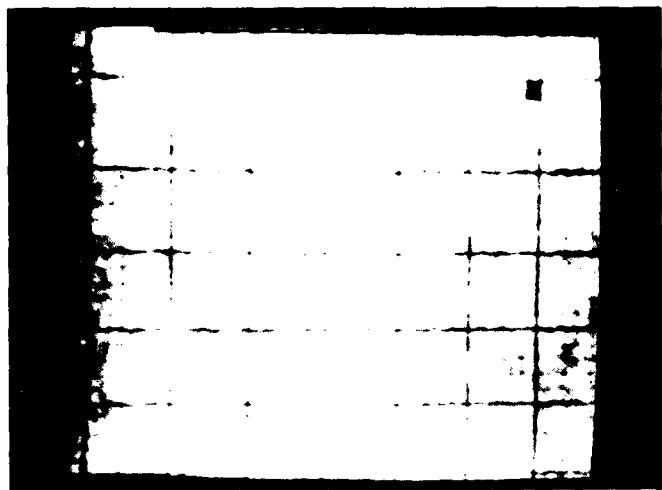


(a) Received image from a live transmitted image.

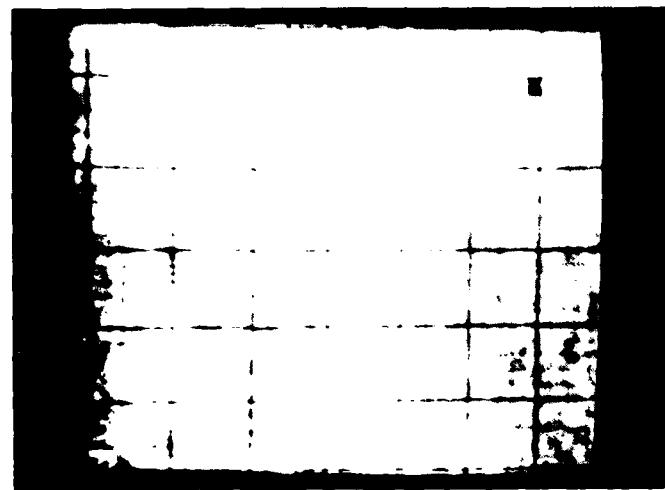


(b) Received image from a transmitted video disc recorded image.

Figure 14. Received image of graph paper test pattern, fine, analog transmission mode, hf.

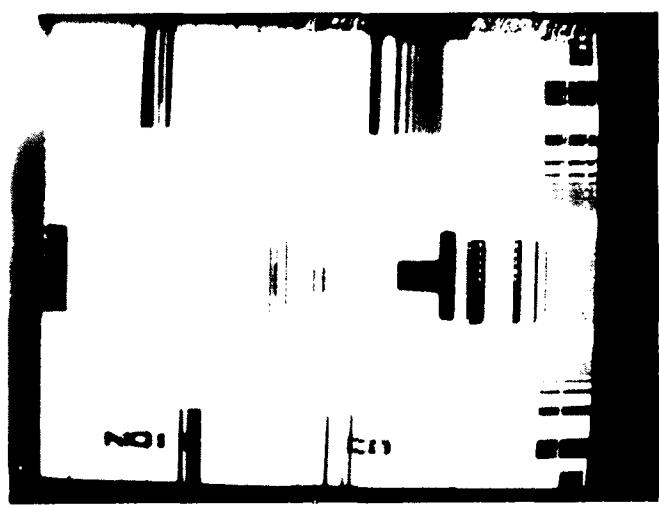


(a) Received image from a live transmitted image.

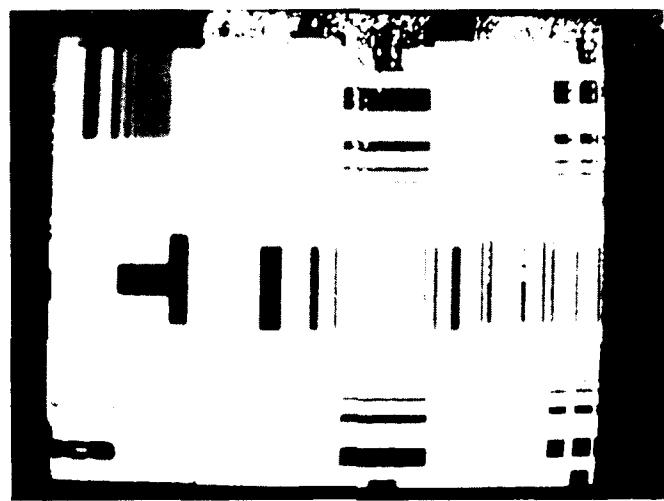


(b) Received image from a transmitted video disc recorded image.

Figure 15. Received image of graph paper test pattern, fine, digital transmission mode, hf.



(a) Fine

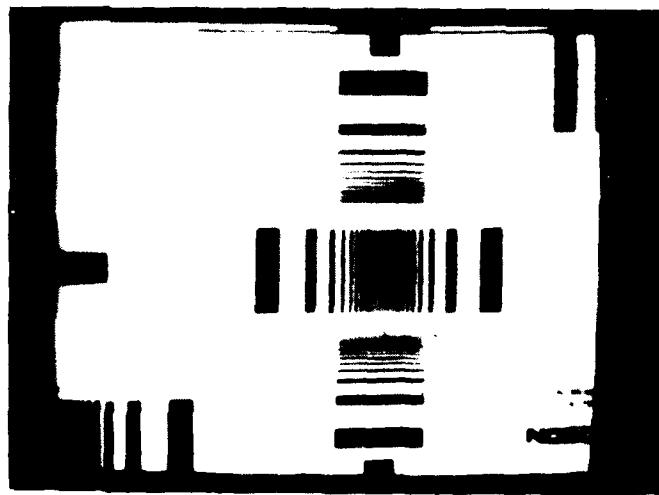


(b) Coarse

Figure 16. Received image of Horizontal Resolution Test Pattern.
live, analog transmission mode, hf.

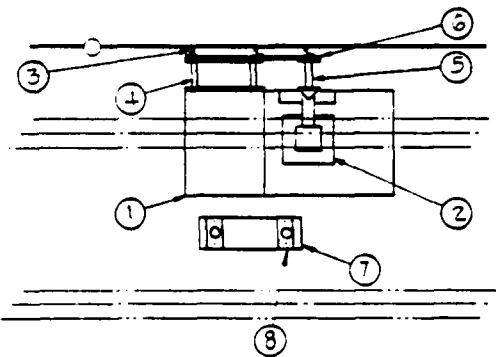


(a) Fine



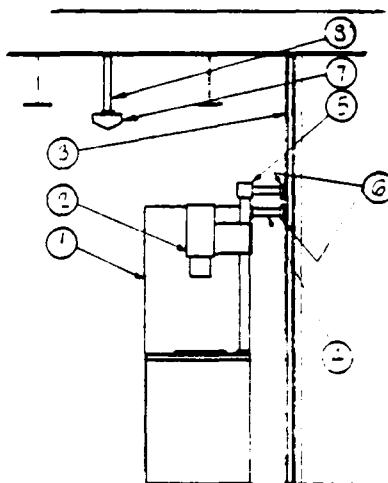
(b) Coarse

Figure 17. Received image of Horizontal Resolution Test Pattern, live, digital transmission mode, hf.

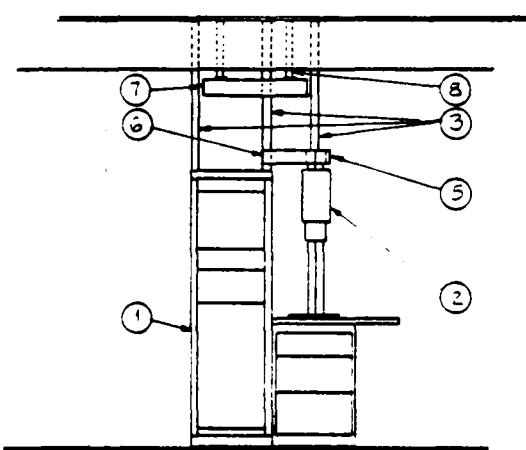


Top View

1. Equipment Cabinet
2. Camera
3. Floor-to-Ceiling Beams
4. Cabinet Back Sway Braces
5. Camera Support Sway Braces
6. Crossmember Between Floor-to-Ceiling Beams
7. Overhead Light
8. Light Foundation



Side View



Front View

Figure 18. RMDS shipboard equipment configuration.

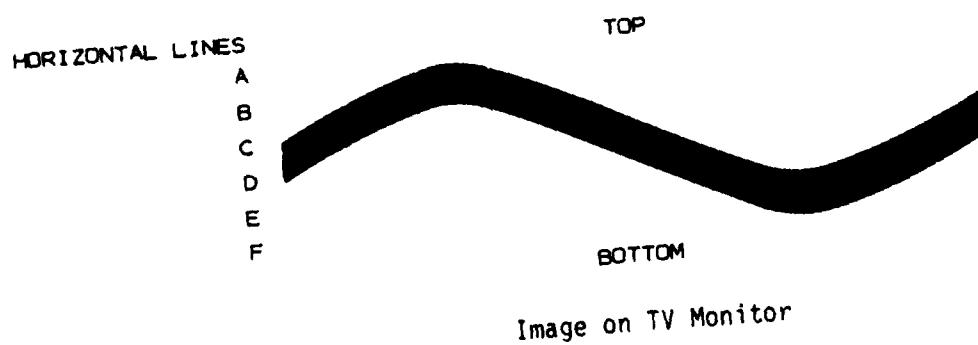
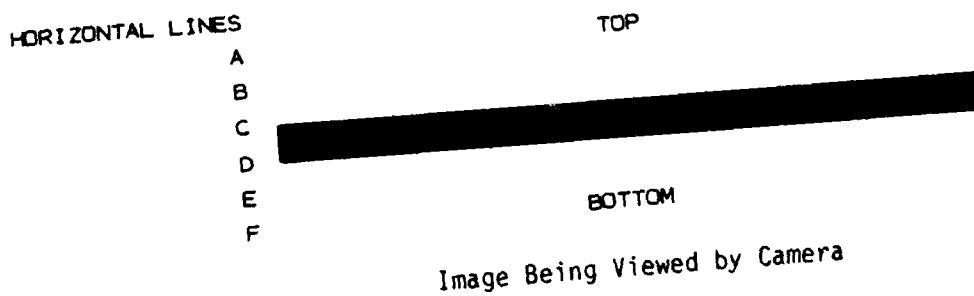
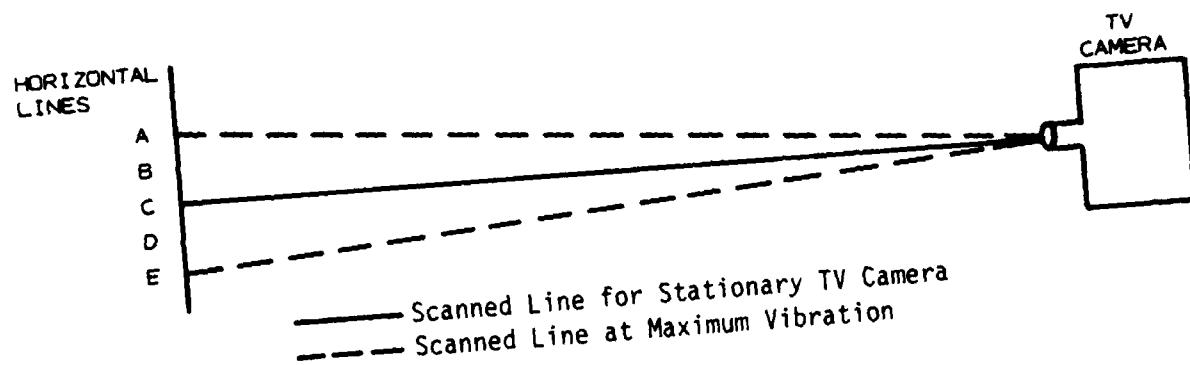


Figure 19. Effects of camera vibration in vertical axis.

for video disc recorded images, as seen later in figures 21 and 22. The image transmitted via the video disc recorder represented a single TV camera scan of the image, whereas the image transmitted live represented repeated sampling of TV camera field scans over the duration of the transmission period. This accounted for the increase in vibrational distortion for live image transmission.

Figures 16 and 17 compare fine and coarse resolution for analog and digital transmission modes. Analog image reception was greatly affected by rf burst noise, whereas digital image reception was affected to a lesser degree by the same noise. Rf burst noise affected image reception in two distinct ways. First, this noise produced a loss of synchronization between the RMDS terminals, requiring image retransmission. Second, noise destroyed the received image along vertical lines. Both forms of image distortion occurred in the analog transmission mode (figure 16), thus preventing a comparison of fine and coarse resolution for the analog transmission. A comparison of fine versus coarse resolution for the digital transmission mode (figure 17) shows similar quality for both fine and coarse resolution modes.

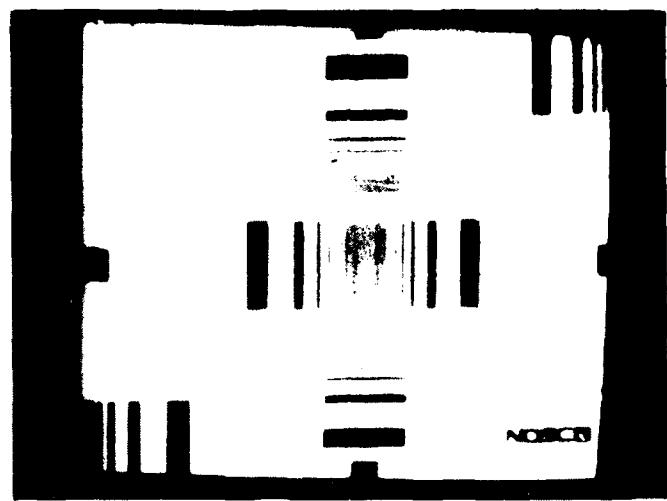
3.3.2 Uhf/Satellite Transmission

Testing of the uhf/satellite communication link was conducted only during a single 4-hour period, since there were difficulties in obtaining uhf/satellite transmission time (see section 2.3.2). The RMDS terminals operated in the live, fine resolution, digital (2400 bps) transmission mode. Both main and remote cameras were used for image transmission, but only a small number of transmissions were performed via the remote camera. The video disc recorder and coarse resolution mode were not tested, since the available testing time was limited.

The quality of received images via the uhf/satellite communication link was generally good, with less distortion due to rf noise than was encountered with an hf communications link. Figures 20 through 23 are representative photographs of transmitted/received images produced by the main and remote cameras as image sources. The RMDS terminals had the ability to produce a gray scale electronically at the beginning of image transmissions, which corresponded to the left edge of the receiver's TV monitor; however, excessive rf noise retriggered several transmissions of the gray scale during a single slow-scan transmission. As a result, the gray scale pattern appeared at different positions on the received image (figure 20, bottom). Images produced with the gray scale pattern turned off at the transmitting terminal were received without this form of image distortion (see figure 20, top).

Vibrations aboard ship caused horizontal waviness in the received images when the TV camera was used as a live image source (see figures 20 and 21, received images). This was similar to the waviness seen via the hf communication link. Figure 21 shows transmitted and received images of a gray scale test pattern. Ten distinct gray levels could be observed for the transmitted and received images, meeting the gray scale specifications called for in the Remote Medical Diagnosis System ADM specification.

Figure 23 illustrates qualitative performance produced by using the remote TV camera in the sick bay as an image source. A comparison of the transmitted and received images demonstrates good quality for the remote TV camera. The effect of noise on uhf/satellite image reception was less than that observed over hf. Weak rf interference did produce a loss of a few scanning lines in the received image. Strong rf

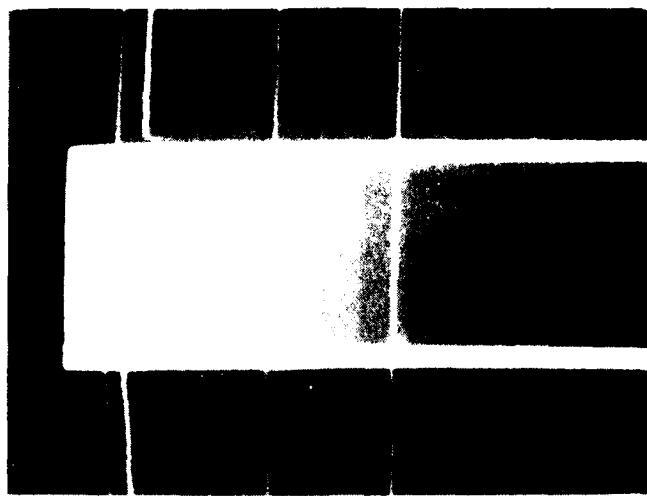


(a) Received image (gray scale pattern off)

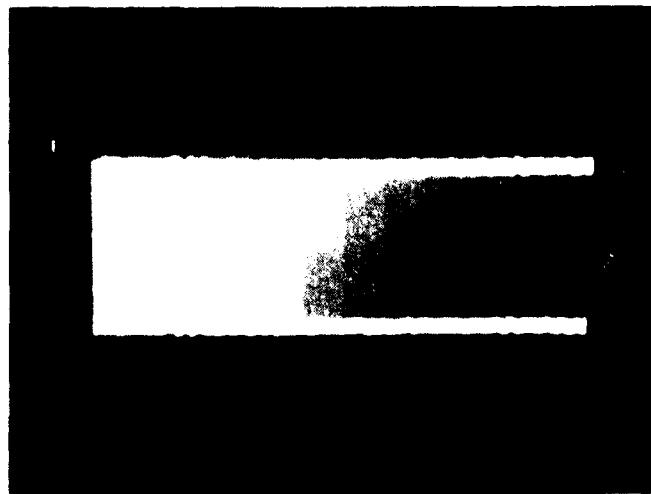


(b) Received image (gray scale pattern on)

Figure 20. Received image of Horizontal Resolution Test Pattern, live, fine, digital transmission mode, uhf/satellite.



(a) Transmitted image



(b) Received image

Figure 21. Transmitted/received image of Gray Scale Test Pattern,
live, fine, digital transmission mode, uhf/satellite.



(a) Transmitted image



(b) Received image

Figure 22. Transmitted/received image of skull X-ray, live, fine, digital transmission mode, uhf/satellite.



(a) Transmitted image



(b) Received image

Figure 23. Transmitted/received image of sick bay, remote camera, fine, digital transmission mode, uhf/satellite.

interference produced a loss of crypto synchronization, which necessitated retransmission of the image.

3.3.3 Image for Varied Zoom Settings

The ability to image the Horizontal Resolution Test Pattern (figure 24) was examined at the two zoom settings, ie far and close fields of view. Images were transmitted and received using an hf communication link. Transmission occurred via the digital, fine transmission mode; the main camera was used to view the test pattern. Figures 25 and 26 show photographs of the transmitted and received images. The received images clearly demonstrated the ability of the zoom lens to magnify areas of an image with good quality. Waviness, similar to that mentioned in section 3.3.1 (figures 14 and 15, live image), was observed in the received images. It was attributable to camera vibration aboard ship.

3.3.4 Video Recorded Data Via Remote Camera

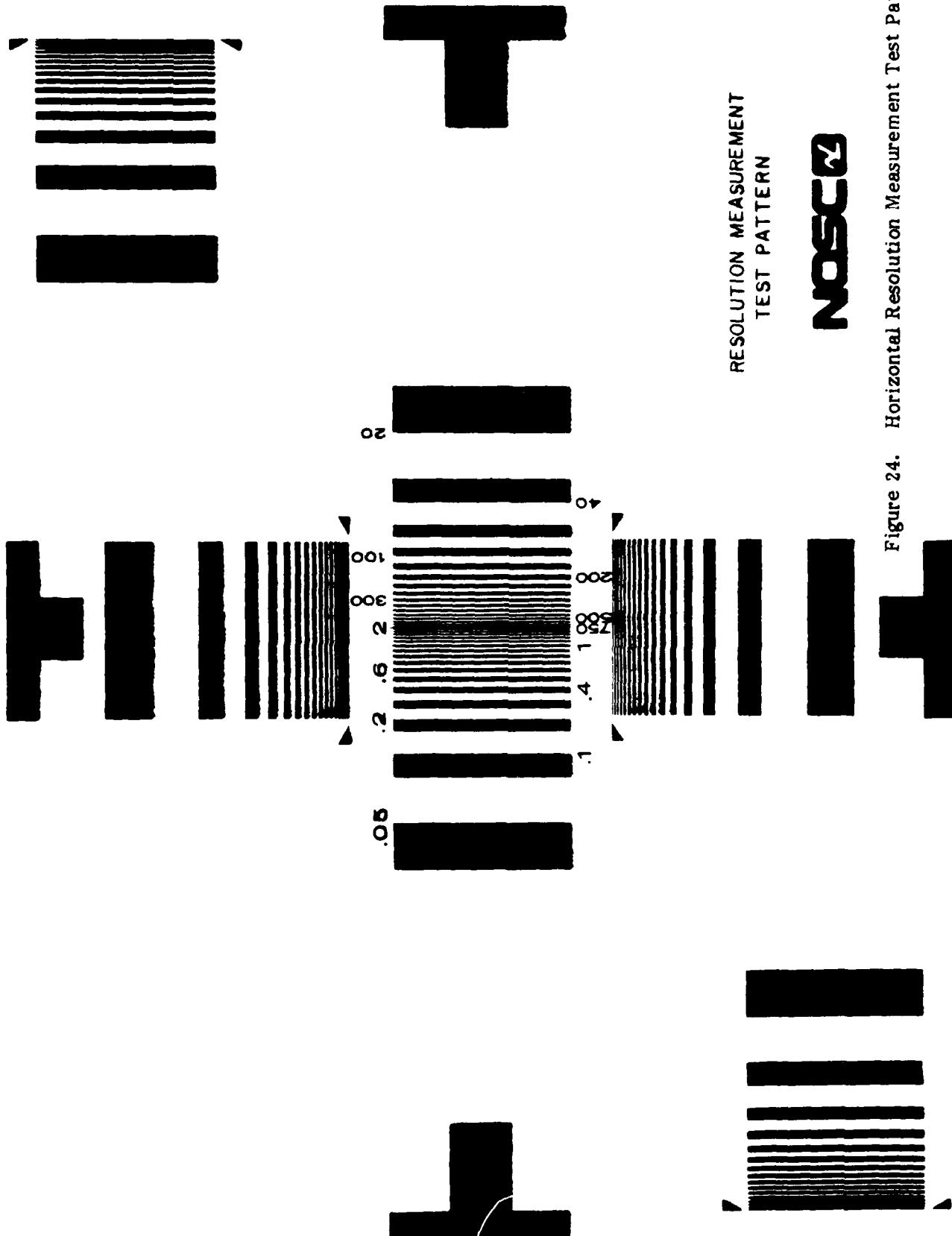
A human subject was employed during tests of image transmission for the remote camera. Images were transmitted and received via an hf communication link. Prior to transmission, all images viewed by the remote camera were stored on the video disc recorder. Figures 27 through 30 are representative photographs of transmitted and received images of the subject. A comparison of the transmitted versus received images demonstrated good quality for image transmission via the remote camera. As stated in section 3.3.1 for figures 21 and 22, the use of the video recorder reduced the effect of camera vibration in the horizontal direction. Similarly, no horizontal waviness was observed in the received images of the remote camera.

3.3.5 Clinical Evaluation of Radiographic Imagery

A series of five radiograph images was transmitted from the main camera of the shipboard RMDS terminal. Each radiograph was evaluated at NOSC by two radiologists from NRMC, San Diego; the images are represented in figures 31 through 35. These received images were transmitted digitally at 2400 bps in the fine resolution mode. Comments rendered by these radiologists indicated that the images were of "sufficient quality to permit adequate diagnosis." However, each radiologist expressed the opinion that more than one view of the same image content might be required for a complete medical diagnosis. Following is the diagnostic interpretation for each radiograph, as provided by CAPT FH Gerber, MC, USN, Head, Radiology Department, NRMC, San Diego. Following Dr Gerber's descriptions are diagnostic interpretations of the received radiographic image by CAPT D Schwarz, MC, USN, and LCDR S Hilton, MC, USNR, both of NRMC, San Diego.

Case One (Sinus with Sinusitis), figure 31. Dr Gerber: The film for this case showed a significant opacification of the left portion of the face. This could be attributed to either sinusitis or swelling of soft tissue. Due to the lack of a sharp demarcation of the opaque area, sinusitis was concluded to be the most probable diagnosis, barring any other clinical data to support other diagnoses. No true indication of facial fracture appeared; however, in the case of the swelling of soft tissue due to a concussion, this could be a logical possibility.

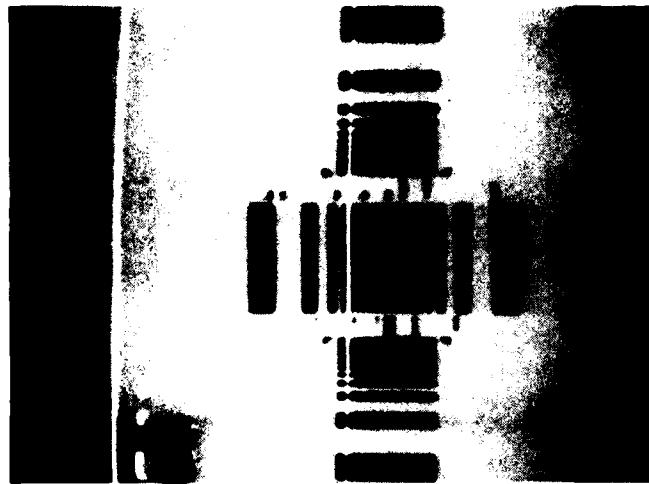
Dr Schwarz: "Cloudy left maxillary sinus. If history is rule-out sinusitis, diagnosis confirmed, patient has left maxillary sinusitis. If history was for trauma, then may need more detailed orbital floor. Film quality sufficient for sinusitis evaluation."



RESOLUTION MEASUREMENT
TEST PATTERN

NOSC

Figure 24. Horizontal Resolution Measurement Test Pattern.

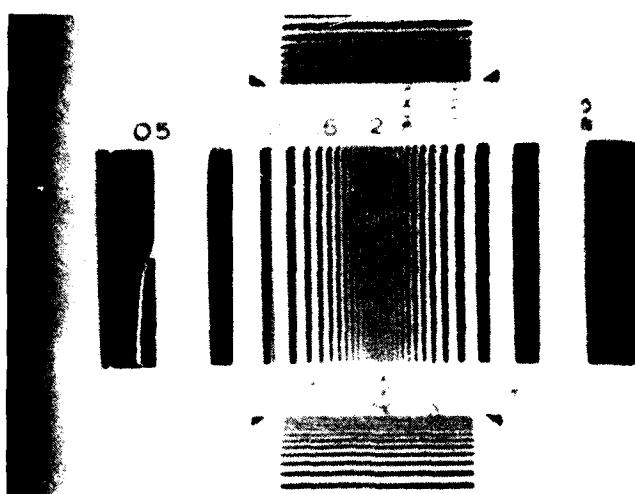


(a) Transmitted image

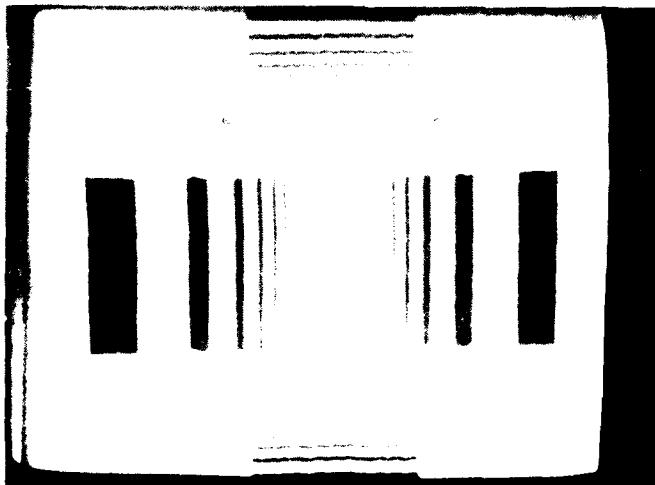


(b) Received image

Figure 25. Transmitted/received image of Horizontal Resolution Test Pattern, main camera far field, fine, digital transmission mode, hf.



(a) Transmitted image



(b) Received image

Figure 26. Transmitted/received image of Horizontal Resolution Test Pattern, main camera close field, fine, digital transmission mode, hf.



(a) Transmitted image



(b) Received image

Figure 27. Transmitted/received image of head and shoulders.
video disc recorder, remote camera, digital
transmission mode, hf.



(a) Transmitted image

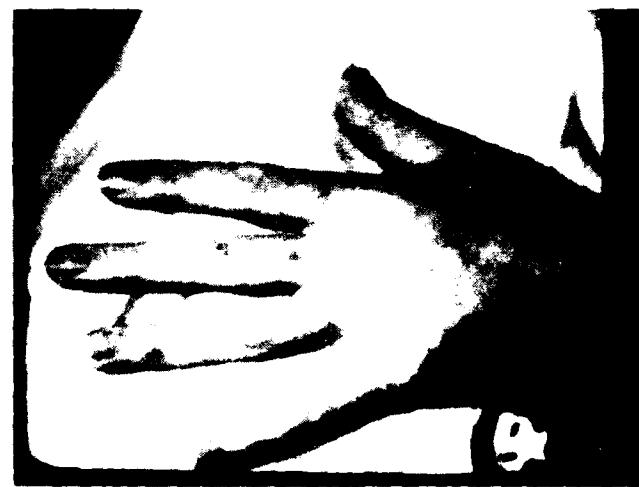


(b) Received image

Figure 28. Transmitted/received image of lower leg and ankle,
video disc recorder, remote camera, digital
transmission mode, hf.



(a) Transmitted image



(b) Received image

Figure 29. Transmitted/received image of hand,
video disc recorder, remote camera,
digital transmission mode, hf.



(a) Transmitted image

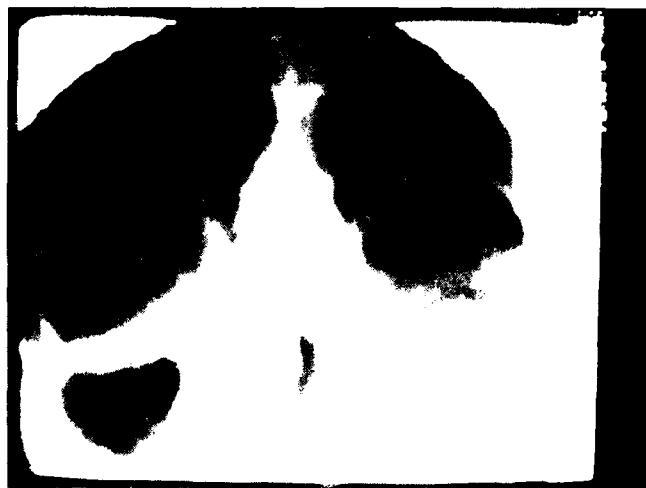


(b) Received image

Figure 30. Transmitted/received image of eye,
video disc recorder, remote camera,
digital transmission mode, hf.



(a) Transmitted image



(b) Received image

Figure 31. Transmitted/received image of radiograph
Case One (sinus with sinusitis).

Dr Hilton: "Left maxillary sinus opacification. Cannot tell whether this is secondary to fracture. Another view would be necessary if patient has had trauma. Satisfactory for diagnosis of sinusitis."

Case Two (Pelvis with Fracture of Right Pubic Ramus), figure 32. Dr Gerber: The film showed a very subtle fracture of the right pubic ramus. Although there were no clear fracture lines, the indications were slight gradations of gray scale and detail in the shape of the ramus. There was a possibility of misdiagnosis of an intertrochaneric fracture of the left femoral neck due to the fact that a line, representing the edge of the fatty tissue of the buttocks, crossed the femoral neck and gave the appearance of a fracture. This misdiagnosis would be rejected upon careful examination, however, since the line could be seen to extend outside the femoral neck.

Dr Schwarz: "Right pubic ramus fracture. Right pelvic hematoma. Questionable inferior ramus fracture -- would require second X-ray (oblique), but quality adequate for evaluation."

Dr Hilton: "Fracture of right superior pubic ramus. Questionable inferior ramus fracture. Adequate X-ray image. Clinical situation in this case would necessitate other views, but this X-ray is good for demonstration of fracture."

Case Three (Chest - Normal), figure 33. Dr Gerber: This film was of a normal female chest with no significant visual clues which could have been mistaken for any of the diagnoses to be evaluated.

Dr Schwarz: "Diaphragm and costophrenic angles cut off -- would need second transmission to include base of lungs. Questionable case of calcification -- suggest lateral view. Image quality adequate except that 6 bit resolution makes evaluation of ribs difficult."

Dr Hilton: "Normal chest. Adequate image. Ordinarily would have asked to see another image with ship's camera centered lower to see lung bases."

Case Four (Chest with Active Tuberculosis), figure 34. Dr Gerber: In this film, the upper lobe of the right lung contained two 2-centimeter-in-diameter radiologic opacifications, generally beneath rib structures. The shape and structure of these opacifications indicated active tuberculosis, but could also be suggestive of bacterial pneumonia or pleural plaque.

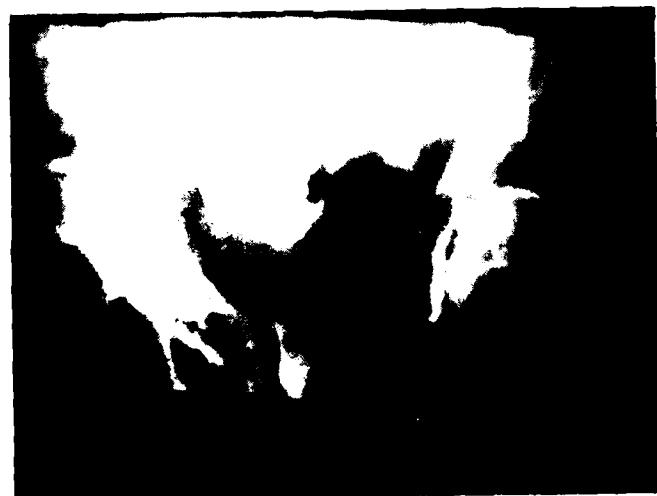
Dr Schwarz: "Questionable right apical infiltrate -- possible TB. Quality sufficient -- would request apical lordotic view."

Dr Hilton: "Questionable right apex nodule. Possible TB. Otherwise normal. Good image."

Case Five (Skull with Fracture), figure 35. Dr Gerber: This lateral film showed numerous long (up to 5 centimeters) and distinct fractures located in the center and back of the skull. The pineal body was not calcified, and as such, the pineal displacement diagnosis was meaningless.

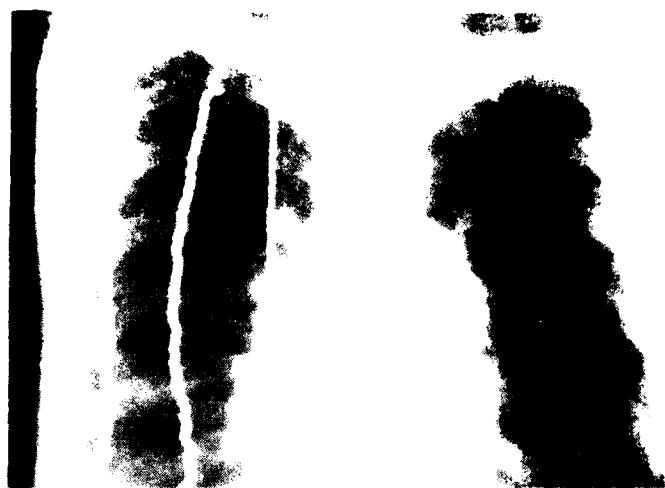


(a) Transmitted image



(b) Received image

Figure 32. Transmitted/received image of radiograph
Case Two (pelvis with fractured right
pubic ramus).



(a) Transmitted image



(b) Received image

Figure 33. Transmitted/received image of radiograph
Case Three (chest - normal).

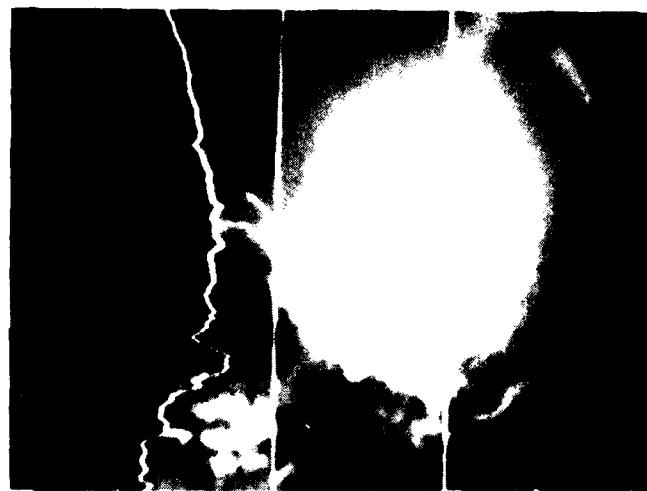


(a) Transmitted image



(b) Received image

Fig. 34. Transmitted/received image of radiograph
Case Four (chest with active tuberculosis).



(a) Transmitted image



(b) Received image

Figure 35. Transmitted/received image of radiograph
Case Five (skull with fracture).

Dr Schwarz: "Parietal skull fracture. Questionable second fracture posterior. Quality of cranial vault good. Detail for bone of skull limited. Small fracture detail limited."

Dr Hilton: "Temporoparietal skull fracture. Image good enough for this big fracture. A subtle fracture could be missed with this quality image. However, I don't know that missing a subtle fracture would have practical significance in patient care."

3.3.6 Operational Problems Encountered

When transmitting video imagery, there was no difficulty in setting up the image to be transmitted. However, false triggering of the RMDS receiver was a problem. Two equipment operating difficulties were reported. First, after an image had been received and displayed on a monitor, vertical streaks began to appear throughout the image. The cause of such "streaks," or tearing of the image, was attributable to false triggering of the receiving equipment by hf noise. Second, hf noise caused restart of the received image during reception of that image. Thus, large portions of the already received image were lost. Prior to or at the beginning of an image transmission, a 2-second duration 480 Hz tone was transmitted for the purpose of activating the receiver preparatory to receiving an image. The receiver circuit had a bandpass filter centered on 480 Hz for the purpose of detecting the start of image transmission. Noise of sufficient amplitude provided enough spectral energy through the filter to trigger the receiver. The results of these reception difficulties are illustrated by figure 16; they were overcome by the following simple circuitry modifications.

A manual switch was installed to prevent false triggering into receive for both analog and digital modes. When the manual switch is in the RECEIVE position, the RMDS terminal is allowed to function normally. When this switch is placed in the HOLD position, the RMDS terminal cannot be triggered into the receive state.

An additional circuitry modification was made for selectively inhibiting the autostart function of the RMDS receiving terminal once it is placed in the receive mode. A manual switch was installed to prevent hf noise from retriggering the start of image reception. When the manual switch is in the AUTOSTART-ON position, the RMDS terminal functions normally. When the switch is in the AUTOSTART-OFF position, the RECEIVE mode can be triggered only by pressing the momentary MANUAL RECEIVE pushbutton switch on the main control panel.

Another problem encountered in image transmission was a condition of waviness, apparent only for video images transmitted "live" from the main camera. Such distortions were attributable to vibrations of the camera on the shipboard RMDS terminal (see section 3.3.1).

3.3.7 Shore Based Hf and Uhf/Satellite Testing

Prior to the at-sea tests, NOSC participated in qualitative testing of the RMDS video system via hf and uhf/satellite communication links. For these tests, the RMDS transmitting and receiving terminals were located at the NOSC facilities, wired in a back-to-back configuration. Figures 36 and 37 illustrate the equipment setup used for the hf and uhf/satellite communication links, respectively. The RMDS terminals were operated in the live, fine resolution, digital (2400 bps) transmission mode for the testing of both communication links. The main camera was used for all hf testing; both

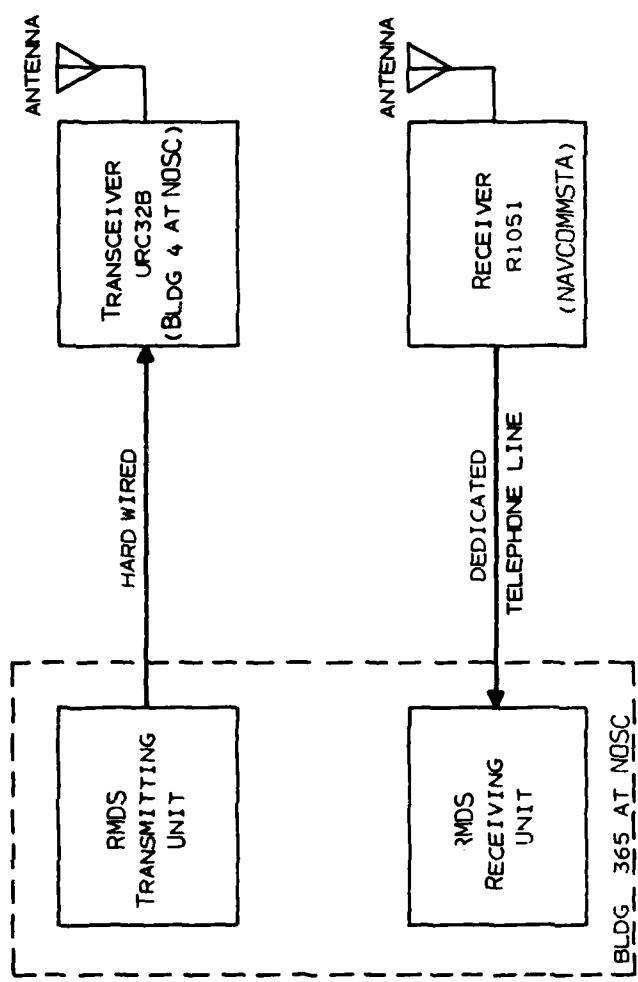


Figure 36. RMDS equipment interface for hf back-to-back testing.

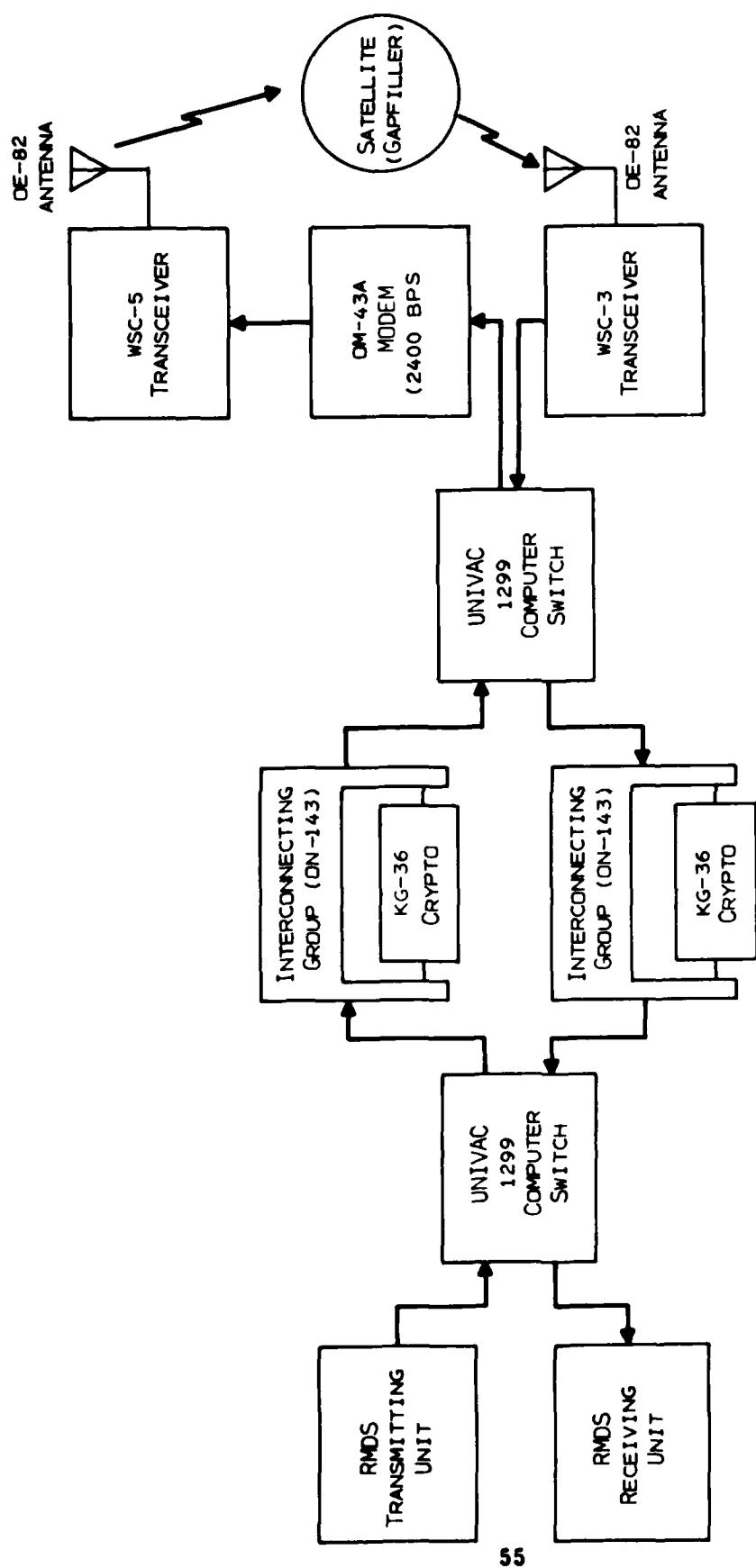
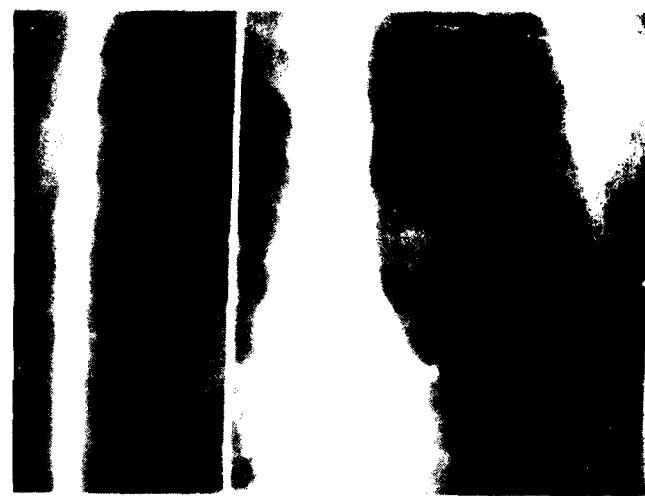


Figure 37. RMDS equipment interface for uhf/satellite back-to-back testing.

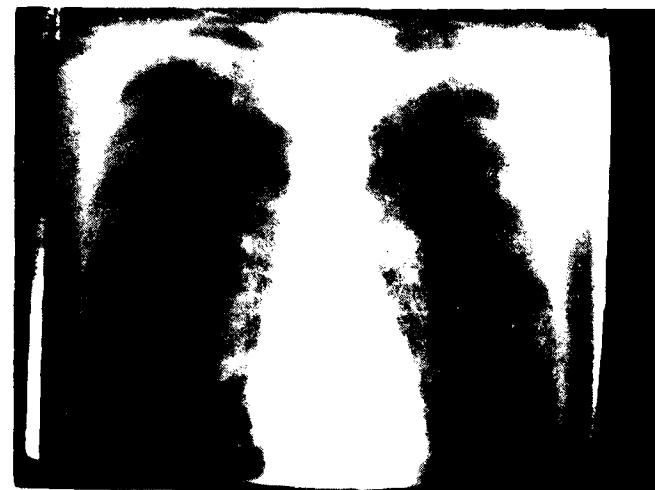
main and remote cameras were employed for uhf/satellite testing. Figures 38 through 40 show representative photographs of the transmitted and received images for the hf communication link; figures 41 through 44, for the uhf/satellite communication link. Figure 45 presents received images of the Horizontal Resolution Test Pattern (figure 24) for both communication links.

The quality of the received images was good for both communication links. Figures 40 and 43 demonstrate the quality of nonradiographic video data transmission for each communication link, and figure 44 depicts a nonradiographic video image from the remote camera. Both communication links supported approximately 0.5 line pair per millimeter of horizontal resolution, as determined from figure 45. Boundary distortion can be seen in radiographs transmitted via both communication links (see figures 38 and 39 for hf, 41 and 42 for uhf/satellite). This distortion was attributed to digital quantization of the video data and was not a function of the communication link.

The uhf/satellite link was superior to the hf link with respect to noise interference. The hf communication link showed the usual problems associated with hf, ie frequency fading, increased noise due to atmospheric conditions, interference from adjacent frequencies, etc. Image distortion caused by noise interference during this testing period was similar to that observed during at-sea testing, ie loss of scanning lines and required retransmission of images. However, image distortion due to noise interference occurred more often during at-sea testing, a condition which was to be expected.

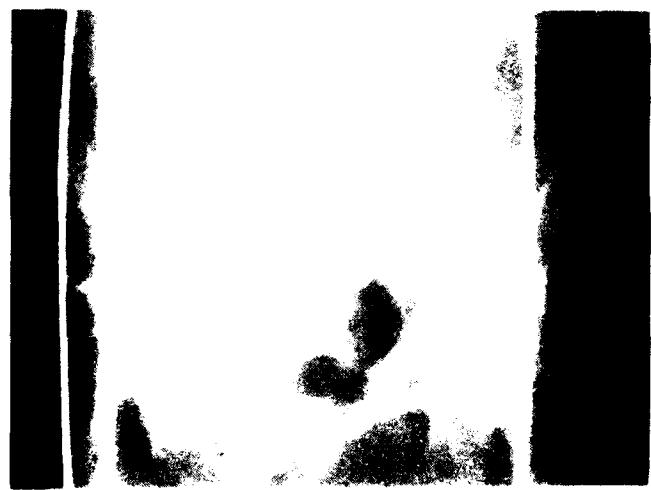


(a) Transmitted image



(b) Received image

Figure 38. Transmitted/received image of chest X-ray,
main camera, digital transmission mode, hf.



(a) Transmitted image

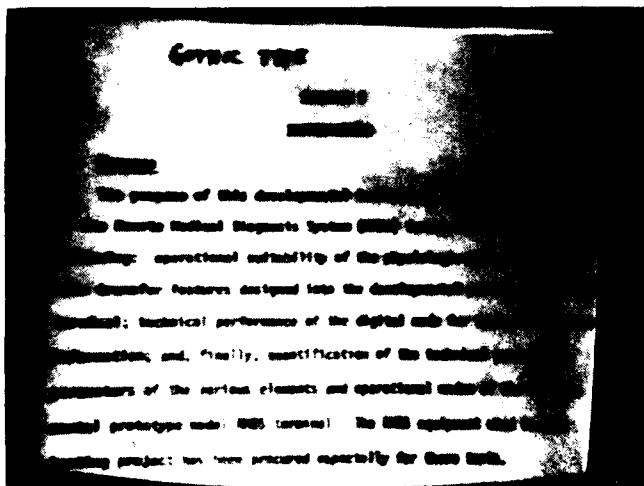


(b) Received image

Figure 39. Transmitted/received image of pelvis X-ray,
main camera, digital transmission mode, hf.

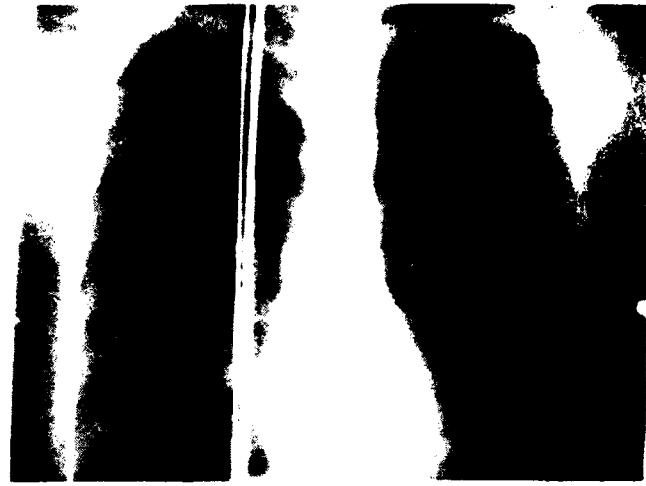


(a) Transmitted image

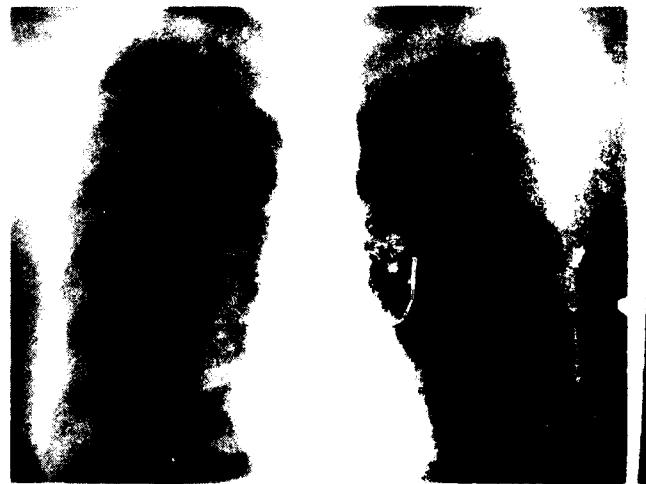


(b) Received image

Figure 40. Transmitted/received image of typed page, main camera, digital transmission mode, hf.



(a) Transmitted image



(b) Received image

Figure 41. Transmitted/received image of chest X-ray,
main camera, digital transmission mode,
uhf/satellite.

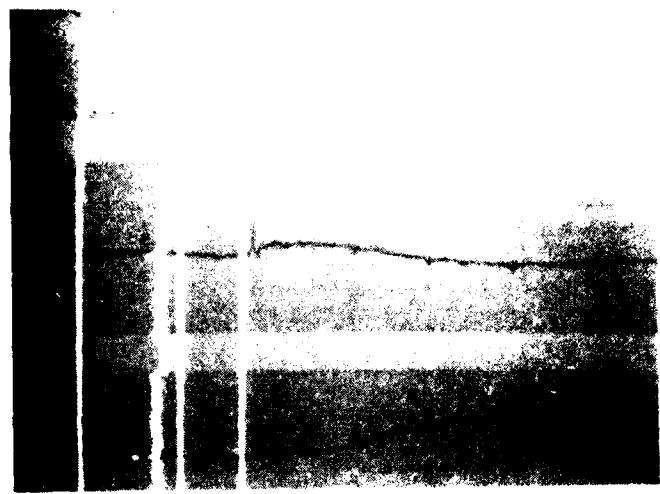


(a) Transmitted image



(b) Received image

Figure 42. Transmitted/received image of pelvis X-ray,
main camera, digital transmission mode,
uhf/satellite.

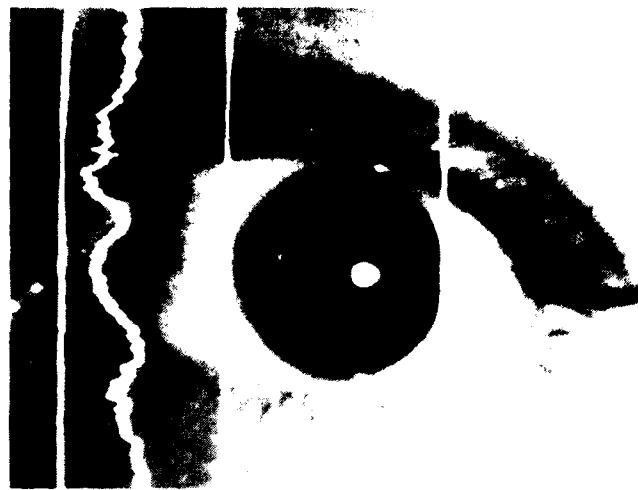


(a) Transmitted image



(b) Received image

Figure 43. Transmitted/received image of ECG signal traces, main camera, digital transmission mode, uhf/satellite.

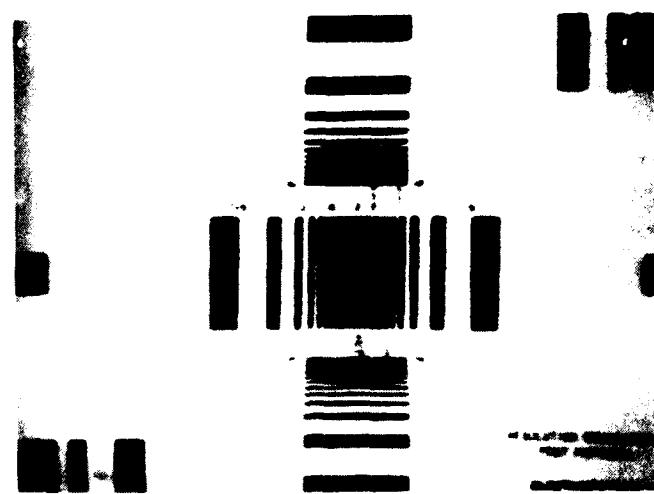


(a) Transmitted image



(b) Received image

Figure 44. Transmitted/received image of eye, remote camera,
digital transmission mode, uhf/satellite.



(a) hf



(b) uhf/satellite

Figure 45. Received image of test pattern, fine, digital transmission mode, hf and uhf/satellite.

SECTION 4

QUANTITATIVE SYSTEM PERFORMANCE

Quantitative testing was performed on the ECG, stethoscope, and video image modes of data transfer. The RMDS ADMs were measured for harmonic distortion (ECG and stethoscope), received noise levels (ECG and stethoscope), and signal-to-noise ratio (video imagery).

4.1 ELECTROCARDIOGRAM

4.1.1 Harmonic Distortion

Tests were conducted to determine the amount of harmonic distortion present in the RMDS terminals and communication link during operation in the ECG transfer mode. The RMDS transmitting and receiving terminals were linked via hf communication configurations. A Wavetek VCG Model II signal generator was used to apply a 0.3 volt rms 25 Hz signal to the ECG input jack of the transmitting terminal. Because of the low signal level of the ECG output jack at the receiving terminal, a Grass P15 AC preamp was used to boost the signal for analysis. The output of the preamp was measured with a Hewlett Packard (HP) Model 311A distortion analyzer, and distortion was recorded in percent total harmonic distortion (THD).

Harmonic distortion tests were performed five times for the ECG transmission mode, under the test conditions mentioned above. The results of the harmonic distortion tests were as follows:

- 3.5% THD
- 4.0% THD
- 3.0% THD
- 3.0% THD plus hf burst
- 100% THD

Difficulty in establishing a low-noise communication link resulted in the 100% THD measurement; the received ECG signal was very distorted and appeared to be off-frequency when observed on an oscilloscope. During another of the harmonic distortion tests, periodic 5 volt peak-to-peak hf noise bursts upset the THD meter, and measurements of total harmonic distortion were obtained between hf noise bursts.

4.1.2 Noise Levels

Testing was performed to determine ECG noise levels, including system drift, in the received signals of the RMDS terminals and communication link. The RMDS transmitting and receiving terminals were linked via an hf communication link. A shorted plug was placed on the ECG input jack at the transmitting terminal; the ECG output of the receiving terminal was monitored with a Hewlett Packard Model 311A distortion analyzer, where measurements of rms noise levels were obtained.

Noise measurements were complicated by the high ambient levels of rf noise that existed at the NOSC facility, as discussed in section 2.2.2. Along with NOSC facility ambient noise, three additional forms of noise were observed during ECG and stethoscopic noise tests:

- 0.2 volt peak-to-peak, 60 Hz square wave pulse harmonics
- 1.0 volt peak-to-peak hf burst noise
- 0.4 volt peak-to-peak (mostly 12 MHz) noise

The origin of this noise was not known, but three possible sources include 1) the RMDS terminals, 2) ambient noise sources at the NOSC facility, and 3) ambient levels of noise picked up by the shipboard RMDS terminal.

Measurements of noise levels, excluding the above mentioned noise, ranged from 0.7 to 40.0 millivolts, with no system drift observed during any ECG testing. By referencing the noise levels to an ECG signal of 1.0 volt, the signal-to-noise ratios for ECG transmission ranged from 63.1 to 28.0 dB, representing only minimal signal distortion.

4.2 STETHOSCOPE SOUNDS

4.2.1 Harmonic Distortion

Tests were conducted to measure the amount of harmonic distortion in the received stethoscope signals caused by the RMDS terminals and communication link. The RMDS transmitting and receiving terminals were linked via an hf communication configuration. A Wavetek VCG Model II signal generator was used to supply a signal to the STETH jack of the transmitting terminal, and a Hewlett Packard 331A distortion analyzer was used to measure the output at the receiving terminal's STETH jack.

Harmonic distortion measurements increased with increases in the modulation frequency (input signal frequency). Values obtained for harmonic distortion were as follows:

Modulation Frequency (Hz)	Harmonic Distortion (%)
50	5 - 6
100	6 - 10
500	8 - 20

The above values also reflect all noise source inputs. This accounted for the range of distortion measurements for each modulation frequency, since there were variations in the noise levels per test condition.

Figure 46 illustrates a typical frequency modulation (FM) energy spectrum, where signal information is contained in discrete sideband spectral lines. The odd-order lower spectrum lines are equal in amplitude but reversed in phase from the upper

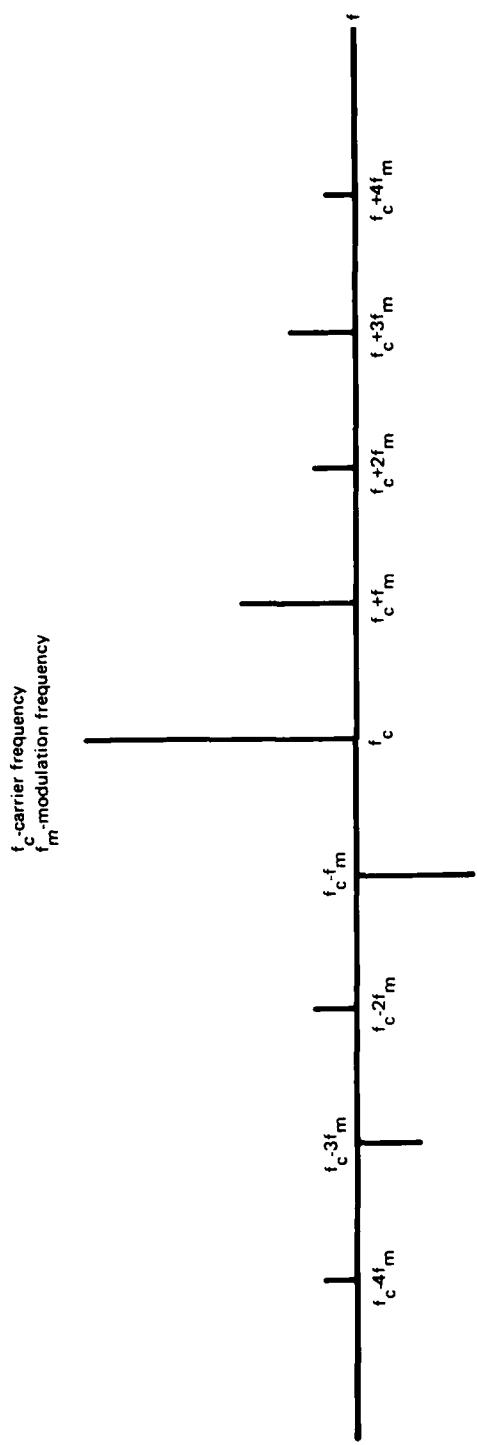


Figure 46. Typical FM line spectrum.

spectral lines. These sideband spectral lines are located above and below the carrier frequency (f_c) at intervals equal to the modulation frequency (f_m). Elimination of the more distant sidebands, due to bandwidth limitations, will result in a loss of signal information.

The bandwidth required for FM transmission of a specific signal is dependent on a ratio of signal amplitude (A_m), modulation frequency (f_m), and the maximum carrier frequency deviation (Δf). In order to determine this bandwidth, it is necessary to know the modulation index, defined as follows:

$$\beta = \frac{A_m f \Delta}{f_m} .$$

The modulation index can be used to determine the number of significant discrete sideband spectrum lines necessary for faithful signal transfer. An estimate of the bandwidth requirement, B, may be mathematically represented as follows:

$$B = 2M_\beta f_m, (M_\beta \geq 1)$$

where B represents bandwidth and M_β represents the number of significant sideband spectrum lines for a particular modulation index. Figure 47 illustrates the bandwidth requirement versus modulation frequency for a maximum signal deviation of 450 Hz (used by the CVI system). The number of significant sideband spectrum lines were obtained from a graphic representation of M versus β (ref 7). Experimental studies have indicated that line A in figure 47 would be a conservative estimate of the transmission bandwidth requirements, whereas line B may result in small but noticeable distortion.

Increases in harmonic distortion that accompany increases in modulation frequency or decreases in bandwidth may be due to the modulation scheme employed and/or the distortion characteristics of the communication link. The CVI system utilizes an FM modulation scheme with a carrier frequency of 1950 Hz and a 450 Hz frequency deviation. Due to amplitude and frequency distortion characteristics, the usable range of frequencies on an unconditioned telephone line lies between 300 and 3000 Hz. With a carrier frequency of 1950 Hz, the usable bandwidth for faithful FM transmission would be approximately 2100 Hz, ranging from 900 to 3000 Hz (upper limit for unconditioned telephone line transmission). The maximum modulation frequency for a 2100 Hz bandwidth, as seen in figure 47, would range from 250 Hz (conservative) to 750 Hz (noticeable distortion). This could account for the increases in harmonic distortion observed during testing.

Laboratory testing of the CVI system (ref 8) has indicated limited capability for stethoscopic transmission. The frequency response is flat for input frequencies lying between 4 and 100 Hz, with the -3 dB point at approximately 700 Hz.

-
7. Communication Systems, AB Carlson, McGraw-Hill, Inc., 1975.
 8. Remote Medical Diagnosis System (RMDS): Test Report, WT Rasmussen (NOSC) and RL Crepeau (WESTEC Services, Inc.), November 1977.

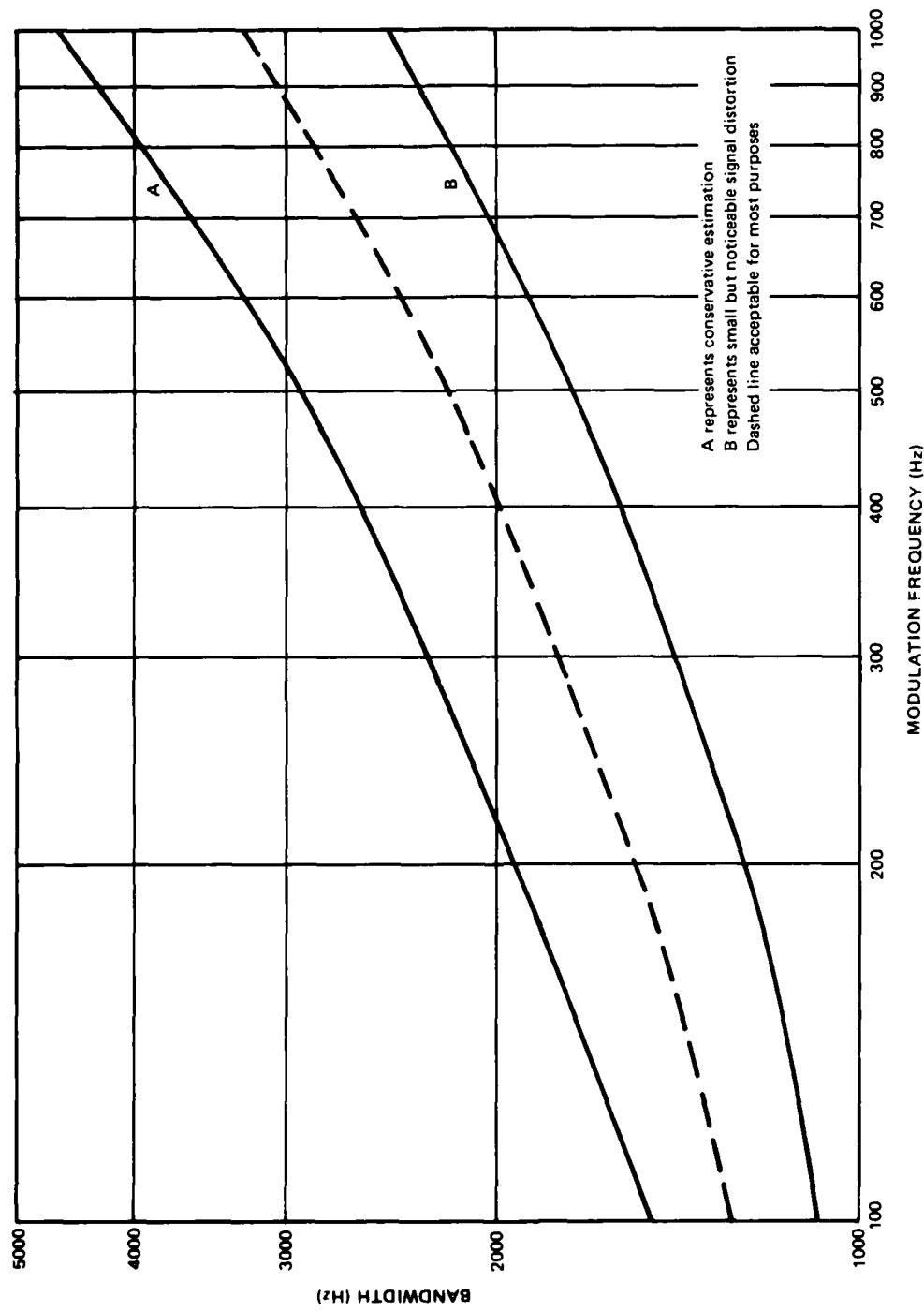


Figure 47. FM bandwidth requirements versus modulation frequency.

The amplitude of input signal during testing was less than the maximum obtainable for stethoscopic transmission, and an increase in frequency response distortion would be expected with increases in signal amplitude.

4.2.2 Noise Levels

Tests were conducted to measure the received noise levels of the RMDS terminals and communication link when operating in the stethoscope signal transfer mode. The RMDS transmitting and receiving terminals were linked via an hf communication configuration. A shorted plug was placed on the STETH input jack at the transmitting terminal. Noise measurements were taken at the stethoscope output of the receiving terminal, using a Hewlett Packard 331A distortion analyzer. Noise level measurements were complicated by ambient levels of rf noise at the NOSC facility (section 2.2.2) and the three additional forms of noise described in section 4.1.2 (ECG Noise Levels).

Measurements of stethoscopic noise, excluding those mentioned above, ranged from 5 to 40 millivolts rms. With these noise levels referenced to an RMDS stethoscope signal of 1.0 volt, the signal-to-noise ratios for stethoscope transmission ranged from 46.0 to 28.0 dB, representing only minimal signal distortion.

4.3 VIDEO IMAGERY

Testing was done to determine the signal-to-noise ratio for video images transferred via hf and uhf/satellite communication links. The RMDS terminals were set up for video transmission, with analog and digital modes used for hf and the digital mode used for the uhf/satellite communication link. The Horizontal Resolution Measurement Test Pattern (figure 24) was used to set the TV camera for optimum image presentation, then the test pattern was removed from the viewbox to transmit a blank image. An oscilloscope was used to measure the noise level of the saturated white video signal in a sample horizontal line through approximately the middle of the image. The SNR for a video signal, rated in dB, is defined as follows:

$$\text{SNR} = 20 \log (E_v/E_m),$$

where E_v is the peak-to-peak amplitude of the picture signal, ie, white saturation level and blanking level, and E_m is the rms value for the noise signal. The signal-to-noise ratios determined by the above method were as follows:

<u>Test Condition</u>	<u>SNR (dB)</u>
hf (analog)	26.0
hf (analog)	33.0
hf (digital)	32.9
uhf/satellite (digital)	28.1

It should be recognized that sources of noise under at-sea conditions were difficult to identify and varied considerably from time to time. It would have been helpful to obtain estimates of rf communication conditions; without such information, varied estimates of noise are less meaningful as judged against the total spectrum of noise available to the system. More data obtained under each condition would be needed for adequate characterization of the SNRs for these conditions.

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SECTION 5

HUMAN FACTORS PERFORMANCE

The Human Engineering Questionnaire found in NOSC TD 395 (ref 2) was completed by four individuals participating in the at-sea testing of the RMDS. A sample copy of this questionnaire is included as appendix B to this report. Numerous discrepancies were cited for the RMDS terminal configuration, type of controls, and method of operation. Listed below are representative criticisms.

- Question: Is the relationship between controls and their associated displays immediately apparent? If NO, does this cause any problem in using or learning to use the equipment?

Answer: "It requires more time to learn than is necessary. Also, some functions require two or three control settings."

Answer: "After 13 months of operation there are times when mistakes in setup for transmission are still made due to the large quantity of controls."

- Question: Have the displays on this equipment been designed so that when they fail it is immediately apparent?

Answer: "Most of the controls are position switches and do not indicate any function failures; some controls do have indicator lights."

Answer: "I feel that an alarm system should be connected so when one component fails it can be more readily detected."

- Question: Does reflection or glare create any problem with this equipment?

Answer: "Will create a problem for the camera during a transmission."

Answer: "Occasionally if the lights in the room are on there may be some reflection from the monitor screen."

Because of the small sample population participating in the Human Engineering Questionnaire and the numerous discrepancies reported herein, a human factors engineering analysis was performed for the RMDS terminals. The results and recommendations obtained from this analysis have been incorporated into the RMDS EDM system specifications.

ONE PAGE

SECTION 6

SUMMARY

6.1 COMMUNICATIONS CHANNELS

RMDS testing used hf and uhf/satellite communication links. Transmission via a uhf communication link was not performed because uhf transceivers were not available aboard USS ENTERPRISE during the RMDS test period. During hf transmission, a single hf link was alternately used for both voice and data transmission; during uhf/satellite testing, the uhf/satellite link was used for data transmission in conjunction with an hf voice communication link.

RMDS testing was noticeably disrupted by noise interference in hf communication links. Hf noise interference was primarily observed in the form of burst noise and interference from nearby hf frequencies. Several hf frequencies were tried before each RMDS test in order to obtain a relatively good communication link. This search involved an extended period of time, ranging from 1.5 to 3.0 hours. Both rf noise and hf interference were observed in ECG, stethoscope, and video transmission modes of operation.

The uhf/satellite communication link also experienced rf interference distortion during video testing. Two forms of image distortion were attributable to rf interference: weak interference produced the loss of a few vertical TV camera scanning lines; and strong interference disrupted cryptographic equipment synchronization, necessitating retransmission of the image.

To accommodate uhf/satellite testing, the narrowband A satellite channel was used. USS ENTERPRISE was equipped primarily for wideband satellite communications, with transmission filters installed to eliminate rf interference. These filters were removed to accommodate RMDS testing over narrowband A; thus, rf interference was no longer eliminated. This rf interference adversely affected RMDS testing at sea.

6.2 INTERFACE CONSIDERATIONS

RMDS interfacing aboard ship was provided by a C1138B/UR radio control unit. It was determined that balanced transmitter/receiver lines were required for proper operation. Extensive feedback encountered between the audio speaker and the microphone aboard ship was eliminated by disconnecting the external speaker and using a headset and/or handset.

Several problems were encountered in the interface between the RMDS shore terminal and NAVCOMMSTA San Diego equipment. Low signal levels were encountered when the initial shore interface configuration was employed (figure 3); amplification of this signal resulted in feedback (hf receiver noise), rekeying of the transmitter during ship-to-shore transmission, and a disruptive ringing during shore-to-ship communication. Four approaches were taken to minimize the feedback problems, and they are discussed at length in section 2.3.4. The final shore interface, shown in figure 4, consisted of a direct-dial telephone line between NAVCOMMSTA and NOSC (used to transmit information shore-to-ship), and a second dedicated telephone line between these two

facilities (used to receive information ship-to-shore). This arrangement decreased the effects of feedback and ringing but did not eliminate them completely. A more detailed discussion of the possibilities of additional interfacing units between the NAV-COMMSTA facility and the RMDS terminals can be obtained in NOSC TR 631 (ref 9).

6.3 MODE OPERATIONAL UTILITY

6.3.1 Electrocardiogram

Qualitative testing of the ECG mode showed good utility for data transmission. The received ECG data were relatively faithful in terms of amplitude and frequency. Attenuation of the received ECG signal was observed; greater attenuation was observed for low frequency and negatively moving pulses. Overshoot was also observed on the received calibration pulses, measured at approximately 10%. This overshoot decreased the amount of attenuation in high-frequency pulses. Results similar to those mentioned above are reported in the RMDS laboratory ECG testing (ref 1).

6.3.2 Stethoscope Sounds

A decrease in quality of 53% was observed in the received stethoscopic heart sounds compared to the transmitted sounds (section 3.2). Noise not present in the transmitted recordings was audible on the received recordings.

6.3.3 Video Imagery

In general, the quality of received images was good. Comments rendered by two physicians who viewed radiographs transmitted via the digital, fine mode indicated that the images were of "sufficient quality to permit adequate diagnosis" (section 3.3.5). The quality of transferred images was affected by rf noise interference for both hf and uhf/satellite communication links. Rf noise affected image reception in two distinct ways. First, noise produced a loss of image sync, requiring retransmission of the image. Second, noise produced vertical lines on the received image. The uhf/satellite communication link was affected less by rf noise interference than was the hf communication link.

Waviness was observed in the horizontal axis of the received image when a live image source was employed. This waviness was attributed to camera vibration aboard ship and was present during both hf and uhf/satellite transmissions (section 3.3.1). The use of the video disc recorder reduced this waviness, as shown in figures 14 and 15. The quality of analog and digital transmission modes was similar, although analog image reception was more easily affected by rf noise than was digital.

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9. NOSC TR 631, Remote Medical Diagnosis System (RMDS) Evaluation of the AN/FTA-28 Telephone Terminal Interface, WT Rasmussen, I Stevens (NOSC), and J West (WESTEC Services, Inc.), December 1980.

6.4 QUANTITATIVE DATA

Quantitative measurements of harmonic distortion and noise levels for ECG and stethoscopic transmission modes were complicated by high ambient levels of rf noise found to exist at the NOSC RMDS facility (section 2.2.2). Three noise forms unknown origin (section 4.1.2) were identified during noise level testing. The fact that the RMDS terminals were susceptible to environmental noise was indicated in the laboratory testing report (ref 1). It should be noted that the shipboard environment contained a large number of sources of rf noise interference.

Except for the above mentioned noise effects, favorable results were produced by harmonic distortion and noise level measurements for the ECG transmission mode. Total harmonic distortion measurements averaged 3.4%, indicating minimal signal distortion. ECG noise level measurements ranged from 0.7 to 40.0 millivolts (rms), corresponding to SNRs of 63.1 to 28.0 dB (referencing noise to an ECG signal of 1.0 volt). This indicated that ECG signal transmission was not noticeably degraded by harmonic distortion or noise levels.

An increase in total harmonic distortion was observed for increasing input frequencies in the stethoscope mode (table 2). Noise level measurements for stethoscope signals ranged from 5.0 to 40.0 millivolts (rms), which correspond to SNRs of 46.0 to 28.0 dB referenced to a stethoscope signal level of 1.0 volt. These numbers indicated that stethoscope signal transmission was not noticeably degraded by RMDS terminal and communication link noise. However, the human ear is extremely sensitive and perceives very slight noises; this fact prompted the negative qualitative evaluation by Dr Vieweg.

Signal-to-noise ratios were determined for video transmission via analog and digital transmission modes for hf communications and via the digital transmission mode for the uhf/satellite communication link. SNRs for these conditions, listed in table 2, compare favorably to measurements obtained in laboratory testing (ref 1) for back-to-back and local telephone communication links.

6.5 HUMAN FACTORS

The results of the Human Engineering Questionnaire (ref 2) indicated that numerous discrepancies existed with regard to terminal configuration, types of controls, and method of operation. Representative criticisms are contained in section 5, and a sample copy of the questionnaire is included as appendix B to this report.

<u>ECG Transmission</u>	<u>Measurements</u>
Total Harmonic Distortion	3.0 to 4.0% at 25 Hz*
Noise Levels (rms)	0.7 to 40.0 millivolts
<u>Stethoscope Transmission</u>	
Total Harmonic Distortion	5.0 to 6.0% at 50 Hz 6.0 to 10.0% at 100 Hz 8.0 to 20.0% at 500 Hz
Noise Levels (rms)	5.0 to 40.0 millivolts
<u>Video Transmission</u>	
Signal-to-Noise Ratio	
<u>Test Condition</u>	<u>SNR (dB)</u>
hf (analog)	26.0
hf (analog)	33.0
hf (digital)	32.9
uhf/satellite (digital)	28.1

*Excluding 100% measurement

Table 2. General system measurements for at-sea testing.

SECTION 7

CONCLUSIONS

The following conclusions were derived from at-sea testing of the RMDS ADM terminals:

1. RMDS communications via hf and uhf/satellite links were adversely affected by rf noise interference. To obtain an acceptable hf communication link, an extensive hf frequency search was required, ranging from 1.5 to 3 hours.
2. The RMDS ADM terminals are susceptible to ambient levels of rf noise, generated either by the terminal itself or by environmental sources at the shipboard or shore facility.
3. Electrocardiogram signal transmission was of sufficient quality for diagnostic purposes, with tolerable levels of attenuation, overshoot, harmonic distortion, and noise (rms).
4. Received stethoscope signals were significantly degraded, especially during hf communications. Although harmonic distortion and rms noise measurements fell within marginally acceptable levels, the extreme sensitivity of the human ear prompted an overall negative evaluation of stethoscope transmission quality.
5. The quality of video image transmission was good, especially during operation in the digital, fine-resolution mode via uhf/satellite communication links. SNR measurements were adequate in both analog and digital modes and via both hf and uhf/satellite communication links.
6. Two radiologists viewing X-rays received in the digital, fine-resolution mode indicated that the images were of "sufficient quality to permit adequate diagnosis." However, they noted that the quantization value of 6 bits per picture element may not be adequate for diagnosis of more subtle details.
7. Waviness was observed in the horizontal axis of the received image when a live image source was employed. This waviness was attributed to camera vibration aboard ship. Use of the video disc recorder reduced this waviness.
8. Human factors engineering problems existed with regard to design of the terminal configuration, controls, and method of operation.
9. Balanced transmitter/receiver lines were required for proper RMDS interface aboard ship.
10. Several problems were encountered in the interface between the RMDS shore station and NAVCOMMSTA San Diego. Two dedicated telephone lines between the two facilities reduced, but did not eliminate, the effects of feedback and ringing.

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SECTION 8

RECOMMENDATIONS

The following recommendations are provided as a result of at-sea testing of the RMDS ADM terminals. These recommendations should be incorporated into the RMDS Engineering Development Models (EDMs):

1. Transmission filters or other means must be devised to eliminate excessive rf noise interference during hf and uhf/satellite data transmissions.
2. The EDM terminals must be shielded or other design changes must be employed to protect the terminals from high levels of ambient rf noise at the transmitting and receiving facilities.
3. To provide the best quality video images, only digital transmission should be considered.
4. The video resolution of the system should be, at a minimum, 525 lines by 256 pixels, with 6 bits per picture element; the preferred resolution for more detailed radiographs should be 525 x 512 x 8.
5. The waviness encountered in video image transmission should be eliminated through use of a video disc recorder or through attenuation of vibration aboard ship.
6. To provide diagnostically acceptable quality for stethoscopic heart/lung sounds, either the RMDS EDMs must employ a transmission scheme less sensitive to hf channel characteristics or other measures must be provided to attenuate rf noise interference.
7. Human factors engineering design criteria must be incorporated into the EDMs, in accordance with MIL-STD-1472B.
8. The RMDS interface aboard ship must provide balanced transmitter/receiver lines.
9. NOSC/NAVCOMMSTA data communications should include the use of a telephone terminal interface and other measures recommended in NOSC TR 631 (ref 9).

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SECTION 9

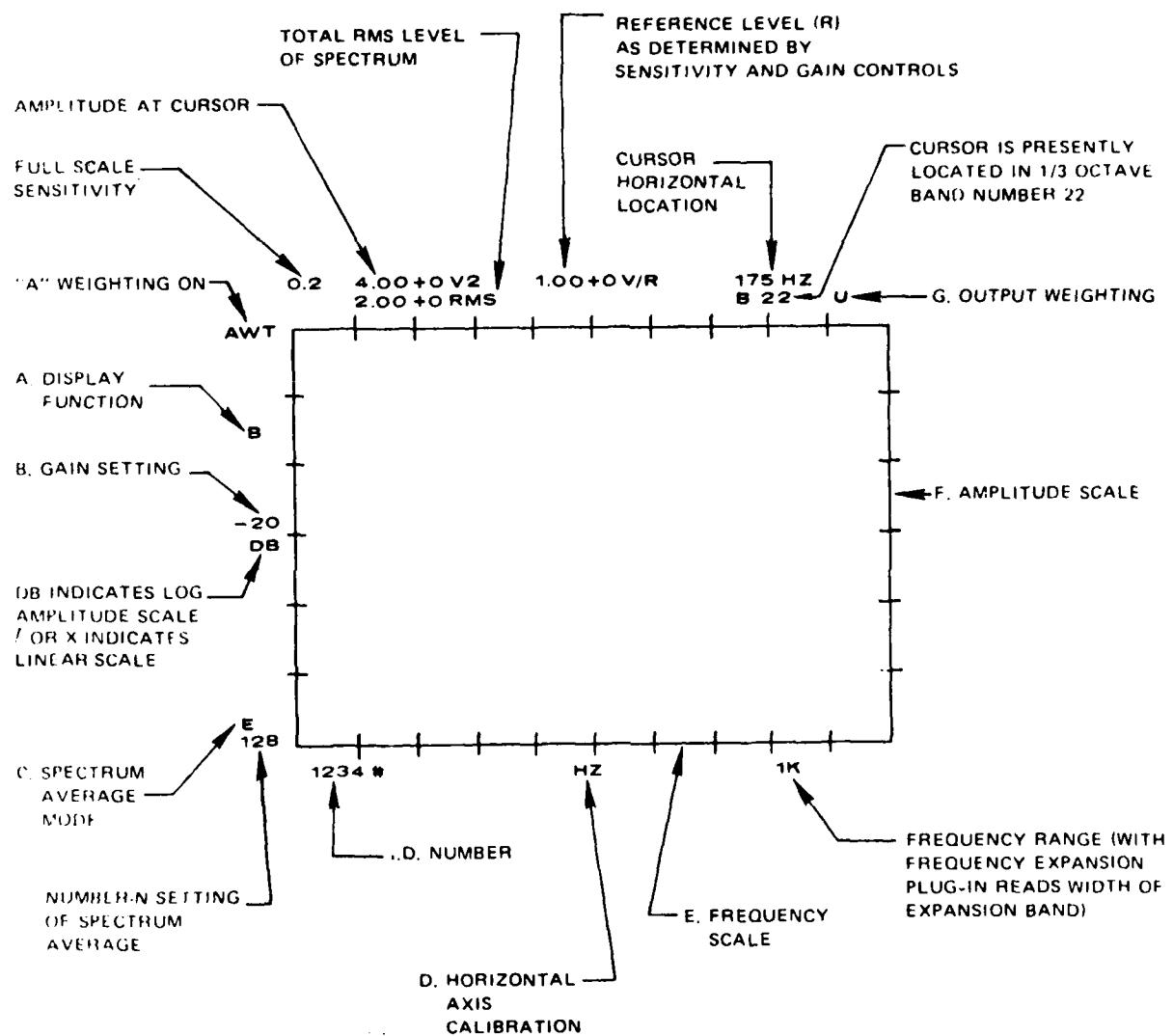
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APPENDIX A

SINGLE SPECTRUM DISPLAY



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APPENDIX B
HUMAN ENGINEERING QUESTIONNAIRE (OPERATOR)

Name _____

Ship/Station _____ Date _____

The purpose of this questionnaire is to get your opinion and observations concerning the human engineering aspects of the RMDS terminals. Answer the questions to the best of your ability. There is no "right" or "wrong" answer. If you need more space to answer a question, use the back of the sheet or additional sheets as necessary. If you have a thought or recommendation which could improve the system, please write it down and turn it over to the Test Director.

1. Is the relationship between controls and their associated displays immediately apparent? Yes ____; No ____; Don't know _____. If NO, does this cause any problem in using or learning to use the equipment? No ____; Yes _____. If YES, explain. _____

2. Is this equipment designed so that functionally related controls and displays are located close to one another? Yes ____; No ____ (Explain).

3. Are the frequently used and critical controls easy to reach? Yes ____; No ____ (Explain).

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WESTEC SERVICES INC SAN DIEGO CA F/G 6/5
REMOTE MEDICAL DIAGNOSIS SYSTEM (RMDS) ADVANCED DEVELOPMENT MOD--ETC(U)
JAN 82 W T RASMUSSEN, I STEVENS, P D HAYES N66001-78-C-0274
UNCLASSIFIED NOSC-TR-690 NL

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HUMAN ENGINEERING QUESTIONNAIRE (Continued)

4. Is the display illumination on this equipment satisfactory for all the conditions under which you must operate it? Yes ____; No ____; Don't know ____ (Explain). _____

5. Have the displays on this equipment been designed so that when they fail it is immediately apparent? Yes ____; Don't know ____; No ____ (Explain). _____

6. If a display circuit fails does it cause a failure in the equipment associated with the display? Yes ____; Don't know ____; No ____ (Explain). _____

7. Can you read all the displays on this equipment to the desired accuracy from your normal operating or servicing position? Yes ____; No ____; Don't know _____. If NO, which ones can't you read? _____

8. Is supplementary lighting or other special equipment required in order for you to gain access or to read any of the displays on this equipment? No ____; Don't know ____; Yes ____ (Explain). _____

HUMAN ENGINEERING QUESTIONNAIRE (Continued)

9. Does reflectance or glare create any problem with this equipment? No ____; Don't know ____; Yes ____ (Explain).

10. Do all the indicator lights, including illuminated pushbuttons, indicate the true equipment response or condition and not just the control position? No ____; Don't know ____; Yes ____ (Explain).

11. Are all the back-lighted indicators on this equipment bright enough to be seen under all operating conditions? Yes ____; Don't know ____; No ____ (Explain).

12. Are any of the indicators on this equipment too bright? No ____; Don't know ____; Yes ____ (Explain).

13. Can all the light bulbs on this equipment be changed easily and rapidly? Yes ____; No ____; Don't know _____. If NO, which ones and why not? _____

HUMAN ENGINEERING QUESTIONNAIRE (Continued)

14. Can the light bulbs on this equipment be removed while power is on and not create any safety hazards? Yes ____; No ____; Don't know _____. If NO, which ones? _____

15. With exception of warning and caution indicators, is the lettering on single legend indicators visible when the indicator is not energized? Yes ____; No ____; Don't know _____. If NO, which ones? _____

16. Are the operator microphones, headphones and telephone headsets designed to permit hands-free operation under normal working conditions? Yes ____; Don't know ____; No ____ (Explain). _____

17. Is there sufficient volume control on all of the communications equipment to permit easy use under all operational conditions? Yes ____; Don't know ____; No ____ (Explain). _____

18. Is there any problem on this equipment with your fingers slipping off push-buttons? No ____; Don't know ____; Yes ____ (Explain). _____

HUMAN ENGINEERING QUESTIONNAIRE (Continued)

19. Do the controls on this equipment give a positive indication of their activation (ie, snap feel, audible click, or integral light)? Yes ____; Don't know ____; No ____ (Explain).

20. Are the labels on this equipment located on or near the items which they identify, so as to eliminate confusion with other items or labels? Yes ____; Don't know ____; No ____ (Explain).

21. a. If writing space is required at any of the consoles, has it been provided? Yes ____; Don't know ____; No ____ (Explain).

- b. If YES, is this space large enough for your needs? Yes ____; No ____ (Explain).

22. Is the working environment (space, temperature, ventilation, noise) comfortable to you? Yes ____; No ____ (Explain).

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